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HARMONY

IT HAS been stated that it is the little things in life that count and such we believe to be the case. Take any of the single wires forming the supporting cables for the Brooklyn bridge and you will observe that it is the size of a piano wire, and consequently does not in anyway indicate a strength sufficient for the work it has to do. Nevertheless, when thousands of these small wires are wound and twisted together we have the combined strength of all, and a strength that is capable of holding up and supporting the tremendous weight of the bridge.

An so it is in any industry, the single individual although playing an important part in a plant could not, working alone, be able to carry out the undertaking, yet with a great many men making up a large complex organization, each of them has their own individual strength and power and the capacity of exercising it in the proper direction. Altogether they present a united front to all conditions that arise and thus are capable of accomplishing wonderful results through unity and harmony.

When Harry S. New, the Postmaster General, declared the other day "the best work can be done only under harmonious conditions," he was uttering a rather good general law. There is no use of trying to play the trombone in the orchestra unless you and all the other players are in harmony. Like Al Jolson used to sing, "You can't play every instrument in the orchestra, but at least you can keep in tune." There is no joy in the home unless there is harmony. You do not have to be beautiful, nor clever, nor interesting, nor even intelligent to get along, but you do have to be harmonious. There is no success in business, there is no fun in a game unless there is harmony. The beauty about harmony is that it does not mean equality,

for in harmony there is a place for the greater and the less, and the wise and the ignorant, the good and the less good. We do not have to be indispensable, but we do have to fit in.

SPIRIT

NO MATTER what you do, you put something of yourself into it.

There are those who put all that they are in whatever they do—and then there are those who merely divide their interests and give and work by half or less. It is the spirit in which you do things that counts more than anything else. Not only for the one you may work for, but for yourself. We can never leave ourselves. Not for a second. Neglect one part of your work and you neglect yourself.

It is the living spirit within us that urges us on that tells us the way to better things, that urges us to rise when we fall and to look up instead of down.

You may make a very bad blunder—but if your spirit was working in the right direction, that blunder can be easily passed by. It is inspiring to meet some people. They seem to have a wonderful inward spirit that is working every minute in their lives. No matter under what condition you meet them, that same even spirit is there. We can all have a happy spirit if we will. It is largely a matter of proper viewpoint and the right consideration of others.

Influence is a wonderful force. And it is the fine spirit that you carry around with you that gives you influence.

WORKERS

IN EVERY chapter there will always be a few individuals because of their own inclination and because they are so situated as to be able to devote time to the interests of the Society who will stand out pre-eminently as instrumental in carrying the message of the Society to those who should be interested, and in this way obtain a large number of memberships for the Society and local chapter. In this connection one of the best examples of conscientious effort and ability directed along this line is exemplified by Norman C. Einwechter of the firm Einwechter & Wyeth, 512 Commerce Street, Philadelphia,

who as a member of the Philadelphia chapter and as a prominent member of the Membership Committee of that chapter has been largely instrumental in contributing to the 80 per cent increase in membership the Philadelphia Chapter has had since September of last year.

Mr. Einwechter very modestly declines credit for any exceptional ability in securing members stating that his entire efforts in the matter have been solely for the benefit and advancement of the man who was actually working in heat treating steel, so that by his becoming a member of the Society he might learn what the outside was doing in new methods, new equipment and new processes in the art and sciences of the manufacture and working of metals. Mr. Einwechter found that practically every corporation interested in the lines followed by the Society, that investigates the teaching the local chapters are advancing to them and their employers, is very glad to support the educational and progressive organization of the A. S. S. T. in promulgating and disseminating practical knowledge of the treatment of metals.

Mr. Einwechter stands very high in the estimation of the members of the Philadelphia Chapter, and they are constantly presenting to him their appreciation of his excellent work during the past year, realizing Mr. Einwechter has placed in his work on the Membership Committee the same enthusiam and energy that has made the firm with whom he is connected such a prominent one in the Philadelphia territory.

In the Hartford Chapter much interest and congratulations are being given to Don Stacks, a consulting metallurgist in that territory, and because of his ability to circulate among the trade has been instrumental in bringing the Hartford Chapter well up in the membership contest by securing sustaining and individual members. Mr. Stacks has always been an enthusiastic member of the Chapter and his work is bringing to him added recognition as to his ability.

FIFTH ANNUAL CONVENTION

PROMISING to invade the Steel City with real enthusiam, members of the A. S. S. T. from every important American and Canadian industrial center will gather at Pittsburgh the second week in October, for the annual convention of the A. S. S. T.

is to be notable not only for its size but for its representation in every phase of steel manufacture and treatment of metals and for the details and consideration that will be given to concrete problems. Organization details are working in a satisfactory manner, and the program is taking shape quite rapidly.

Identification certificates for use of members and guests in securing railroad rate reduction will be sent out to all members of the Society from the National headquarters, and also to others planning to attend the Convention who send in requests for these certificates. Over 6000 will be issued. Certificates are issued on the basis of official requests only, except so far as the members of the Society are concerned. Added to this list to whom railroad certificates will be sent must be added the totals of guests from points near Pittsburgh who will not avail themselves of the rate or those who will desire to return home another way, or to continue their journey to another city.

Pittsburgh has declared itself out to win the National pennant for the best and biggest and most enjoyable National Convention the A. S. S. T. has ever held. Radio invitations will be forecasted inviting the general public to attend the convention and exposition. The Pittsburgh committee co-operating with the National President, T. D. Lynch, and the National Secretary have been working for months in their efforts to present the most comprehensive and complete program ever offered at an annual convention. Morning sessions will be given over to general meetings, while the afternoons will be devoted to round table sessions and symposiums.

The speakers before the general morning sessions will include many men of nation wide reputation. Not only will America be predominantly represented in the program but the convention itself will take on an international aspect inasmuch as papers are to be presented by representative men of England, France, Japan and Germany.

The entertaining program has not been overlooked, every moment not taken up with business meetings or visiting exhibits will be given over to pleasure. The 250 members of the Pittsburgh chapter are exerting every effort to give the visiting members and guests the time of their life. The right hand of good fellowship will be extended. Every minute that isn't taken up

with constructive thought will be devoted to seeing that the visitors carry away a proper impression of the hospitality of Pittsburgh.

The exposition which is to be one of the big features of the fifth annual convention of the A. S. S. T. will open at Monday noon, October 8, and all of the visiting guests and members will participate in the opening exercises. The exposition at Detroit last year was by far the largest that had been held by the Society, yet there has been thirty per cent more space taken for the Pittsburgh show than for the Detroit exposition, and it is confidently believed that by the time the exposition doors are open every available foot of space will be engaged. The exposition has grown to such size and the requests for space have been so heavy that it will be necessary to use two floors in Pittsburgh in order to accomodate the firms desiring to present their products for examination and inspection. On the sub-floor will be located the meeting room of the Society where the afternoon round tables and sessions will be held. A novel feature has been added to the sub-floor in order to make it especially attractive and as a point of interest for the members, so the entire floor is to be given an Egyptian setting and there also is to be located an exact replica of King Tut's Tomb. This combined with the oriental music and other features now being planned will all contribute to adding a spirit of good fellowship and enthusiam to the exposition. At least 20,000 are expected to visit the convention and exposition.

The members of the various Pittsburgh committees who are working so diligently for the success of the 1923 convention and exposition are as follows:

General Chairman

J. Trautman, Jr., Asst. Gen. Sales Manager, Colonial Steel Co. Telephone —Court 0582.

Representatives of Board of Directors A. S. S. T.

T. D. Lynch, Research Engineer, Westinghouse Electric and Mfg. Co.
W. H. Eisenman, National Secretary A. S. S. T.

Chairman of the Meetings and Papers Committee

Prof. Stephen L. Goodale, Prof. of Metallurgy, University of Pittsburgh. Telephone—Schenly 3300.

P. J. Neely, Frank Garrett, J. M. Camp, W. A. Mathias, R. D. McMillen, J. W. Weitzenkorn, C. M. Johnson, and Phiroz Kutar.

Chairman of Finance Committee

Roy C. McKenna, President, Vanadium Alloys Steel Co., Latrobe, Pa. Floyd Rose, Harry A. Kraeling, Dr. B. D. Saklatwalla.

Chairman Entertainment Committee

N. B. Hoffman, Metallurgist & Chemist, Colonial Steel Co.

H. A. Bathgate, W. A. Carter, M. W. Caruthers, Roy H. Davis, Edward H. Fischer, Floyd B. Bowman, R. D. Fennel, D. R. Loughrey, L. A. Way, DuRay Smith, W. J. Prestley, W. I. McInnerney.

Chairman Ladies' Entertainment

J. A. Succop, Metallurgist, Heppenstall Knife & Forge Co. Telephone—Fisk 0916.

R. R. Arts, W. C. Emery, M. F. McOmber, T. S. Tung, John Ludwig, Geo. Hopkins.

Chairman Local Exhibition Committee

Walter Buechner, E. F. Houghton Co. Telephone—Smithfield 1960.

Hugh Rodman, J. B. Moore, D. C. Bakewell, Frank A. Bond, H. R. McMahon, R. H. Pauley, D. H. Horn, Harry S. Hunter, G. L. Kronfeld, Harry L. Barr, W. H. Phillips, R. C. Heaslett, F. C. Riddle.

Chairman Information Committee

D. W. McDowell, 205 Conniston Avenue, Pittsburgh, Pa. Telephone—Grant 5072.

J. J. Jones, Geo. L. Leffler, H. L. Walker, S. B. Phelps and B. F. Weston.

Chairman Transportation Committee

Wallace B. Crowe, Metallurgist, Armor Plate Dept., Carnegie Steel Co. Telephone—Homestead 1211.

C. I. Neidringhaus, A. M. Cox, B. L. Jarrett, and H. C. Loudenbeck

Chairman Hotels Committee

R. E. Polk, Engineering Department, Equitable Gas Co. Telephone—Grant 3200.

R. S. Bedworth, R. W. Dalrymple, C. K. Dunmeyer, Wm. J. Linderfelder, Q. S. Synder, J. W. Taylor, Clarence E. Wise, F. M. Warring, and E. C. Cook.

Chairman Publicity Committee

A. M. Stachle, Publicity Department, Westinghouse Electric Mfg. Co.

H. L. Walker, Secretary General Committee, 1521 Monterey Street, Pittsburgh.

HOTEL RESERVATIONS FOR THE CONVENTION

IN ORDER that our members and guests may be well taken care of during the time of the annual convention of the Society to be held in Pittsburgh, October 8 to 12 inclusive, we are publishing in this issue of the TRANSACTIONS a list of the

WILLIAM PENN HOTEL
Convention Headquarters

hotels at Pittsburgh so that you can make your reservations immediately and thus be sure of accomodations.

In writing to the hotel please state the price and kind of room you wish, and request them to acknowledge your communication confirming the reservation and price.

The hotels in Pittsburgh will be packed to their utmost

capacity to take care of the enormous number who will visit the city during the convention, consequently, we cannot urge you too strongly to make your reservations at once. It will be necessary for you to state that you are attending the convention of the American Society for Steel Treating, otherwise your reservation may be refused.

In case you have difficulty in securing the accomodations you wish, a communication addressed to the chairman of the hotels committee, R. E. Polk, chief industrial engineer, Equitable Gas Company, Pittsburgh, Pa., will receive prompt attention and your wishes will be taken care of.

List of Pittsburgh Hotels

William Penn

(Headquarters)

375	Rooms	with bath,	2 persons,	Rate	$3.50-5.00	each
375	Rooms	with bath,	1 person,	Rate	4.00-8.00	

Fort Pitt

190	Rooms	with bath,	2 persons,	Rate	$2.50-5.00	each
100	Rooms	without bath,	2 persons,	Rate	2.50	each
190	Rooms	with bath,	1 person,	Rate	3.50-9.00	
100	Rooms	without bath,	1 person,	Rate	3.00	

Hotel Henry

12	Rooms	with bath,	4 persons,	Rate	$2.50	each
12	Rooms	with bath,	2 persons,	Rate	3.00	each
24	Rooms	with bath,	1 person,	Rate	4.00	up

Anderson Hotel

20	Rooms	with bath,	4 persons,	Rate	$2.50	each
24	Rooms	without bath,	4 persons,	Rate	2.00	each
10	Rooms	without bath,	2 persons,	Rate	2.50	each
20	Rooms	without bath,	1 person,	Rate	3.00	

General Forbes

17	Rooms	with bath,	4 persons,	Rate	$2.00	each
9	Rooms	with bath,	2 persons,	Rate	3.00	each
24	Rooms	without bath,	2 persons,	Rate	1 50	each
25	Rooms	with bath,	1 person,	Rate	4.00	up

Seventh Avenue Hotel

14	Rooms	with bath,	4 persons,	Rate	$2.50-3.00	each
10	Rooms	with bath,	2 persons,	Rate	2.50-3.00	each
20	Rooms	without bath,	2 persons,	Rate	2.00-2.50	each

Pittsburgh Natatorium

(For gentlemen only)

175 Rooms, with swimming pool, cots, 1 person, Rate $2.00

Monongahela House

10	Rooms	with bath, 2 persons, Rate	$3 00		each
40	Rooms	without bath, 2 persons, Rate	2.00		each

Schenley Hotel

5	Rooms	with bath, 4 persons, Rate	$3.00		each
10	Rooms	with bath, 2 persons, Rate	4.00		each
10	Rooms	without bath, 2 persons, Rate	3.00		each
10	Rooms	with bath, 1 person, Rate	7.00		
10	Rooms	without bath, 1 person, Rate	4.00		

Rittenhouse Hotel

25	Rooms	with bath, 2 persons, Rate	$2.00-3.00		each
20	Rooms	with bath, 1 person, Rate	3.00-4.00		

Y. M. C. A., East Liberty

10	Rooms	without bath, 1 person, Rate	$2.00		

Negri Hotel

25	Rooms,	with bath, 1 person, Rate	$3.00		

New Sixth Avenue

15	Rooms	with bath, 2 persons, Rate	$3.00-4.00		each
15	Rooms	without bath, 2 persons, Rate	2.50-3.00		each
10	Rooms	with bath, 1 person, Rate	3.00		
5	Rooms	without bath, 1 person, Rate	2 00-3.00		

Chatham Hotel

5	Rooms	with bath, 4 persons, Rate	$2.00		each
20	Rooms	with bath, 2 persons, Rate	3.00-5.00		each
20	Rooms	without bath, 2 persons, Rate	2.50-3.00		each
15	Rooms	with bath, 1 person, Rate	3.00		

EASTERN SECTIONAL MEETING WELL ATTENDED

THE Eastern Sectional meeting held in Bethlehem, Pa., June 14 and 15, 1923 under the auspices of the Lehigh Valley chapter of the society proved to be a most successful and interesting meeting from every viewpoint, and was probably the most successful sectional meeting that has been held.

The papers program consisted of two technical sessions, the first being held Thursday afternoon, June 14 at 1:30 p.m. in the University room of the Hotel Bethlehem. The meeting was called to order by A. P. Spooner, metallurgist of the Bethlehem Steel Company and chairman of the Lehigh Valley chapter of the A. S. S. T. who introduced John J. Crowe, metallurgist of Philadelphia Navy Yards, who acted as chairman for this meeting.

An address of welcome was given by Archibald Johnson, vice president of the Bethlehem Steel Company who in a very

cordial manner welcomed the members and guests of the various chapters of the American Society for Steel Treating to Bethlehem. Following Mr. Johnson's talk, President T. D. Lynch remarked briefly in reference to the activities of the American Society for Steel Treating.

The first technical paper of this session was presented by Dr. F. C. Langenberg of the Watertown Arsenal, entitled "Behavior of Metals Under Normal and Sub-Normal Temperatures". The second paper by F. R. Palmer of the Carpenter Steel Company, Reading, Pa., entitled, "Equalization of Internal and External Strains in Tool Steel". The third paper by B. F. Shepherd, Ingersoll-Rand Company, was entitled "Case Hardening". Each of these papers treated their subjects in a most capable manner, bringing forth considerable interesting and valuable discussion. These papers will be published in early issues of TRANSACTIONS.

The evening program consisted of a dinner and entertainment for members, guests and ladies in the ball room of the Hotel Bethlehem. The speaker for this dinner meeting was Dr. E. J. Cattell of Philadelphia who gave a very interesting talk on "America's Progress".

The Friday morning program consisted of an inspection trip through the plants of the Bethlehem Steel Company. The visitors assembled at the Battery building of the steel company at 8:45 for the inspection of the permanent exhibit of products made by the steel company and then proceeded through the various plants of the steel mills. This trip covered the points of interest which were outlined in the May issue of TRANSACTIONS. Luncheon was served at one o'clock in the dining room of the main office of the Bethlehem Steel Company and from there the members proceeded to Drown hall of Lehigh university where the second technical session was held.

Under the chairmanship of Sam Tour this session was called to order and was first addressed by Dr. C. R. Richards, president of Lehigh university who greeted most cordially the members of the society, welcoming them to Lehigh university. The first technical paper entitled "Practical Metallography" was presented by R. H. Christ of the Bethlehem Steel Company, and the second paper entitled "The Develop-

ments of Heat Resisting Metals" was given by Victor Hybinette of the British America Nickel Company of Wilmington. Each of these papers brought forth many interesting features in reference to their subjects and were well discussed after their presentation.

The visiting ladies were well entertained by various trips around Bethlehem including an automobile trip to Delaware

Group of Members Who Attended the Eastern Sectional Meeting Assembled at the Battery Building of the Bethlehem Steel Company, which was the Starting Point of the Plant Inspection Trip.

Water Gap and the historical points of interest in and about Bethlehem. More than 150 members, of the various chapters, but principally those from the eastern chapters attended this meeting and as evidenced by the enthusiasm of all of these members, this sectional meeting was highly successful and bids well for the continued success of the sectional meetings of which this was the fourth.

CRYSTALLIZATION OF IRON AND ITS ALLOYS-I*

By Albert Sauveur

Abstract

This paper describes the dendritic crystallization of iron carbon alloys and its further transformations and calls attention to the importance of its study. It is shown that the properties of steel depend upon its microstructure and its persistent dendritic segregation, and that the latter is not affected by the usual heat treatments, while hot working causes deformation of the segregated areas and results in directional properties. The action of certain reagents in revealing dendritic segregation is explained as well as the relation existing between the dendritic or solidification structure and its microstructure.

Introduction

A TINY drop of liquid iron or of steel should, on solidifying, if it obeyed only the laws of crystallography, be converted into a regular octahedron (Fig. 1). Such perfect crystals with faultless geometrical outlines are called idiomorphic crystals. The octahedron is a form belonging to the cubic or regular (isometric) system of crystallization. Iron and steel like most metals, crystallize in the cubic system. Iron, moreover, when it solidifies, exists in the allotropic condition known as gamma iron. The octahedron, therefore, is the crystalline form of gamma iron. The gradual growth of octahedral crystals has been studied and it has been observed that the main axes are formed first, and that this is followed in quick succession by the appearance of secondary and ternary axes and finally by the filling up of the interstices between the axes, (Fig. 2). If the liquid could be removed before this filling up takes place, we would obtain what is sometimes described as skeleton crystals (Fig. 3).

Crystals grow through the successive addition of small crystalline units symmetrically arranged according to the system of crystalliation to which they belong. If these units are cubic their

*As it is the author's intention to publish other papers on this same subject, he has, for ease in later referring to it, numbered this article: I.

A paper to be presented at the annual convention of the Society, Pittsburgh, October 8-12. The author is professer of metallurgy, Harvard University, Cambridge, Mass. Written discussion of this paper is invited.

corresponding faces will lie in parallel planes. This is called the orientation of the crystals and constancy of orientation is a property of all crystals. Because of this crystalline orientation, crystals possess direction of easy rupture known as cleavage planes. Cubic crystals have three cleavage planes, ABC, DEF,

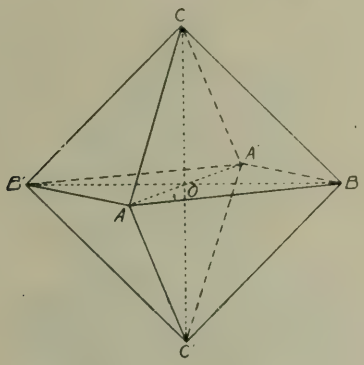


Fig. 1—Regular Octahedron. Perfect Crystals Conforming to such Faultless Geometric Outlines are called Idiomorphic Crystals.

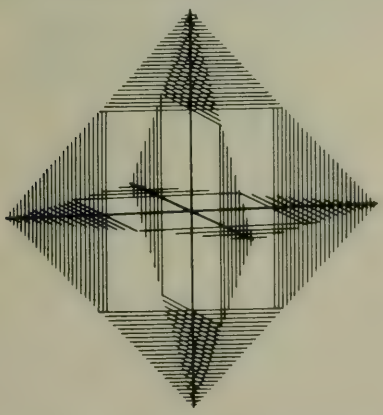


Fig. 2—Gradual Growth of Octahedral Crystals. From Belaiew's "Crystallization of Metals", (After Knop).

and GHI, Fig. 4, parallel to the three sets of faces of the solid. Constancy of crystalline orientation imparts also unlike properties in different directions, that is, causes anisotropy. In the case of the octahedron one may, following Howe, conceive the crystalline units to be cubic, (Fig. 5). Such octahedral crystal would then

have three planes of cleavage parallel to one of the three pairs of faces of the small cubes and four planes parallel to one of the four pairs of faces of the octahedron.

A tiny drop of liquid iron or of liquid steel will not, however, assume, on solidifying, the external form of an octahedron because of contact with the support on which it is solidifying, and

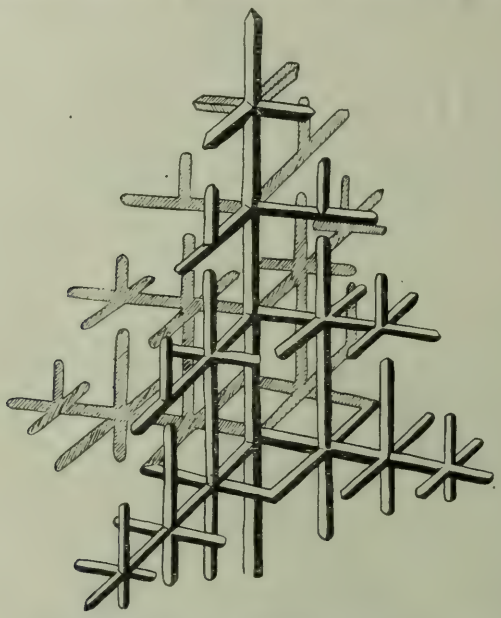


Fig. 3—Skeleton of Octahedral Crystals. (After Tschernoff.)

of other factors opposing the crystallographic forces. It does crystallize, however, and the mechanism of its crystallization is that of the octahedron. Lacking the external geometrical form of perfect, idiomorphic crystals, but retaining a true crystalline structure, they are called allotriomorphic crystals.

If a considerable mass of liquid iron or of liquid steel could be conceived to exist without its container, suspended in space in the form of a liquid sphere or cube, and if crystallization started at the center of the solid and proceeded with equal velocity and without hindrance in all directions, the result would be a single very large idimorphic crystal, a perfect octahedron. Liquid metals, however, must of necessity be held in containers, the form

of which they retain after solidification, notwithstanding the crystallizing forces which would cause them to assume octahedral forms. Assuming that the crystallization of liquid steel in its mold could proceed from one center only, and could complete itself

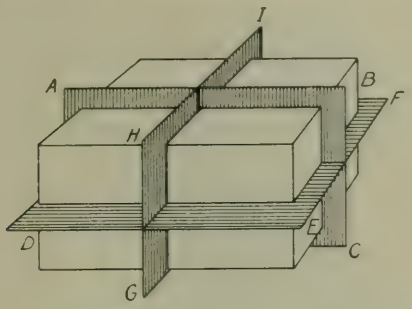


Fig. 4—Cleavage Planes of a Cubic Crystal (After Mellor). Cubic Crystals have Three Cleavage Planes as shown by ABC, DEF, and GHI, Parallel to the Three Sets of Faces of the Solid.

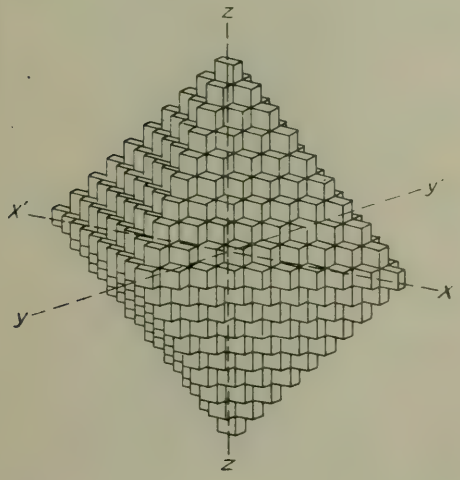


Fig. 5—Octahedral Crystal Composed of Small Cubes (After H. M. Howe). Such an Octahedral Crystal would have Three Planes of Cleavage Parallel to One of the Three Pairs of Faces of the Small Cubes and Four Planes Parallel to One of the Four Pairs of Faces of the Octahedron.

without change of orientation, it would be octahedral in its habit and would result in a single, very large allotriomorphic crystal, having for its external form the internal form of the mold.

Masses of steel made up of but one crystal would probably be very brittle because of the readiness with which crystals can be ruptured along their cleavage planes. They would also inherit the directional properties of single crystals. They would be anisotropic.

Dendrites

When a metal crystallizes, however, in passing from the liquid to the solid state, crystallization proceeds from many centers or nuclei and the solidified mass is finally made up of a great many crystals each one having its own orientation. In the case of iron and steel, if the crystallizing forces could have free play, a perfect octahedron would be formed around each nucleus and the solidified metal would consist of many juxtaposed octahedra. Opposing and disturbing factors intervene, however, such as surface tension and contact with neighboring crystals likewise, in process of formation, which prevent the crystals from assuming regular geometrical forms. In other words, allotriomorphic and not idiomorphic crystals are produced. The mechanism of their formation remains, however, octahedral in character. The disturbing factors mentioned above cause each individual octahedral growth to increase more rapidly in some directions than in others and generally, elongated crystallites known as "dendrites" are obtained as in Fig. 6. They are also called, because of their appearance, "pine" or "fir-tree" crystals. Such fully developed dendrites are generally found in the "pipes" of large ingots hanging to the roof, like stalactites, (Fig. 7). Belaiew describes dendrites as elongated aggregates of octahedra.

Solidified masses of iron or steel, therefore, are made up of a great many dendrites closely interlocked, (Fig. 8 and 9). While each crystal possesses directional properties, while it is anisotropic, the mass as a whole may be considered isotropic, possessing uniform properties in all directions. Directional properties may indeed be imparted to steel as later explained, but this is not due to the anisotropy of the small crystals of which it is made up. It should be borne in mind that the number, size, and form of these crystals, and, therefore, the properties of the castings, will necessarily be influenced by a number of factors, such as composition, initial casting temperature, rate of solidification, etc. It should be further observed that the cooling action of the walls of the mold has a tendency to impart a "radial" or "columnar" structure to

the casting (Fig. 10 and 11), the main axes of the external dendrites being normal to the walls.

It should not be expected that the physical properties of such a casting will be uniform throughout. Test pieces cut from the

Fig. 6—Steel Dendrite. (Reduced ½.) Such Formations are also Called "Pine" or "Fir-Tree" Crystals and are Generally Found in the Pipes of Large Ingots, Hanging from the Roof like Stalactites.

portions of the casting having a radial dendritic structure will of necessity exhibit different properties from those possessed by test pieces cut from the central portion where the dendritic growth

has not been so powerfully influenced by the cooling action of the walls. Steel castings are necessarily structurally heterogeneous.

When it will be shown that the dendritic segregation which accompanies the formation of dendrites cannot be effaced by sub-

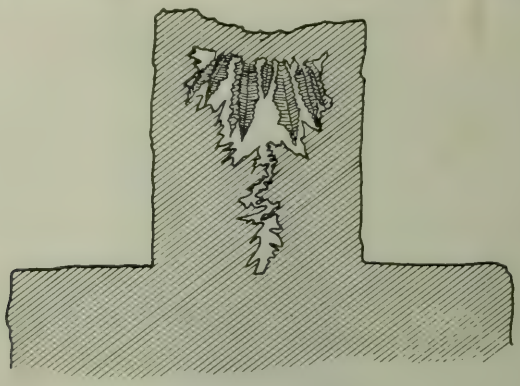


Fig. 7—Steel Dendrites in Sinking Head of Large Ingot. (After Tschernoff.)

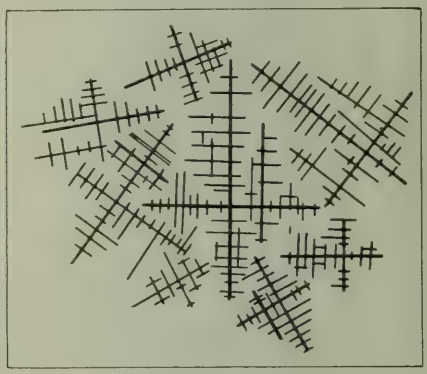


Fig. 8—Dendritic Segregation in Steel. (After Tschernoff.) Solidified Masses of Iron or Steel are Made Up of a Great Many Dendrites Closely Interlocked.

sequent heat treatments, and that its influence persists even after mechanical working, the importance of its study will be readily appreciated.

Mechanism of Dendritic Growth

Let us assume a single dendritic crystal in process of formation, Fig. 12. It is believed on very good ground that the primary

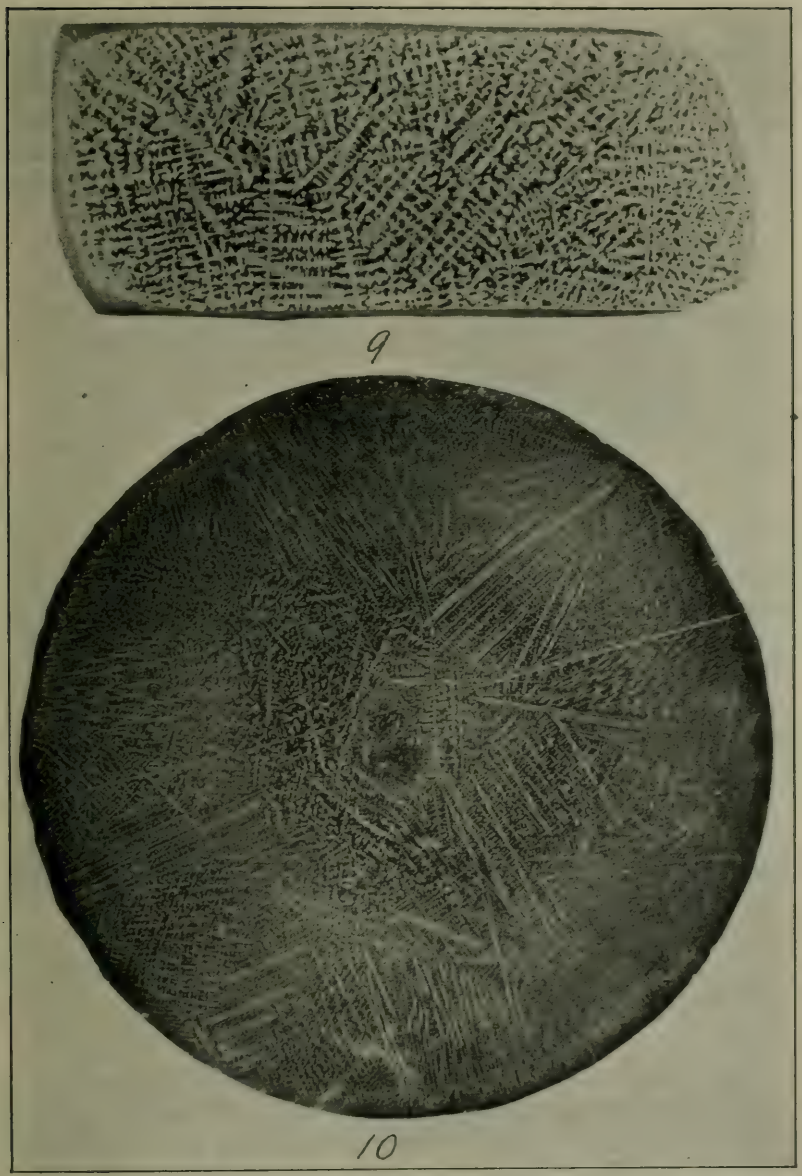


Fig. 9—Dendritic Segregation in Steel, Magnified 2 Diameters. (By V. N. Krivobok in author's laboratory.)

Fig. 10—Radial Dendritic Crystallization in Steel. (After Tschernoff.) The Cooling Action of the Walls of the Mold has a Tendency to Impart a Radial or Columnar Structure to the Casting. The Main Axes of the External Dendrites are Normal to the Walls.

axis forms first and that this is followed quickly by the appearance of secondary and ternary axes. These axes grow and thicken through gradual deposition of cubic or octahedral particles of soild metal until, finally, the interstices between them are filled up in a like manner and the dendrite is completed. Its external shape will necessarily be influenced by eventual contact with neigh-

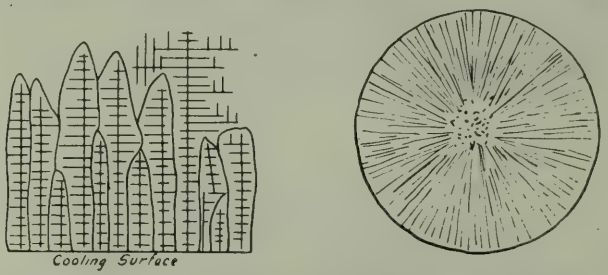


Fig. 11—Sketch Showing the Formation of Radial or Columnar Structure in Steel Castings (After Tschernoff).

boring dendritic growths and boundary lines should exist between them. (Fig. 13). It is, however, only occasionally that these boundary lines can be brought out as in Fig. 14. If the iron is chemically pure, the dendrite will necessarily be *chemically homogeneous* in all its parts, and will form at a *constant temperature,* namely, at the solidification point of iron. If we accept Rosenhain's theory in regard to the existence of an amorphous film or cement between crystals formed from the liquid state, then we must assume that each dendrite is enclosed within an amorphous membrane or bag. While the amorphous theory has been brilliantly conceived and vigorously upheld and while it explains satisfactorily many phenomena, it should not be accepted as proven fact. Let us employ it as a useful tool, and be ready to discard it whenever a better one is at hand.

Detection of Dendritic Growth

Whenever it is possible for crystals to grow freely, without hindrance from neighboring growths, as for instance in pipes of large ingots (Fig. 7), the dendrtic character of the crystallization of iron and steel is clearly revealed. A mass of steel, however, is composed of closely interlocked dendrites and to study its crystallization we must examine polished and suitably treated plane surfaces. Such sections should have the appearance shown in Fig. 9.

When the dendritic character of the crystalization of steel is clearly revealed, these dendrites and their boundaries are generally so large that they can be observed with the naked eye. The structure is then said to be *macroscopic*, to distinguish it from structures so small as to require the use of a microscope for their detection, that is, from *microscopic* structure. We talk, therefore, of macrostructure and of microstructure. The terms dendritic structure and macrostructure, however, should not be used indifferently as having the same meaning because a dendritic structure is not necessarily macroscopic, nor a macrostructure necessarily dendritic. The dendritic structure of iron and steel may properly be called "primary structure" and the large grains enclosed within the dendritic boundaries "primary grains." They are generally macroscopic in size, hence, we may also talk of macro and of micrograins.

The possibility of bringing out the dendritic structure of steel through some suitable treatment of polished sections should be considered. It would seem as if there should be no difficulty in revealing the existence of boundaries between adjoining dendrites because, even in chemically pure metals, those boundaries, if they do not consist of amorphous cement, mark at least changes of crystalline orientation. As already mentioned, however, the existence of these boundaries are often very difficult to bring out. An etching treatment to be effective must necessarily be selective in its action, and in order that it may be selective, the sample under study must be chemically or physically heterogeneous. In the absence of such heterogeneity, selective action by the reagent is impossible and the structure remains hidden. Assuming a dendrite, therefore, perfectly homogeneous in all its parts, physically and chemically, its structure cannot be brought out by etching methods. It should be the case with chemically pure iron. When so called chemically pure iron is considered, however, it is well to remember that such purity is hardly obtainable and that a very small proportion of impurity, possibly little more than a trace, may suffice to produce in the dendrite the necessary heterogeneity required for the selective action of the reagent. It should be further considered that while iron may be reported free, or practically free, from the ordinary impurities it may still contain some gases held in solution and this may suffice to produce dendritic heterogeneity.

Dendrites of Solid Solution

Let us assume a metal or metalloid M′ dissolved in a metal M and let us assume the soluble component M′ to have a lower melting point than the solvent M. As soon as the solidification range of the alloy is reached, dendrites begin to form at many centers, or nuclei, throughout the cooling mass. Let us consider a single dendrite and follow the mechanism of its formation, (Fig. 12). The main axis of the crystal will be the first one to appear

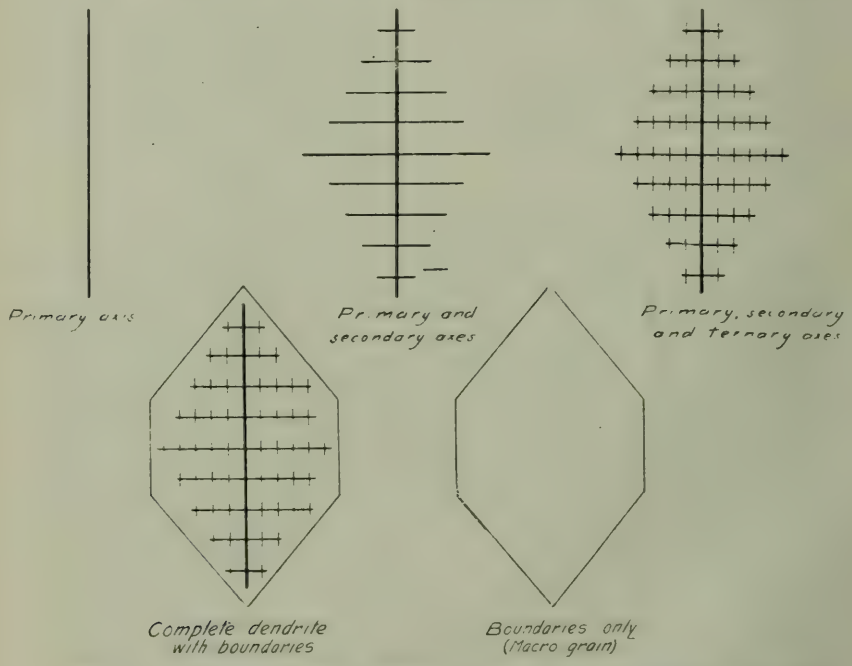


Fig. 12—Diagrammatic Sketch Showing the Growth of a Dendrite. The Axes Grow and Thicken Through Gradual Deposition of Cubic or Octahedral Particles of Solid Metal until Finally the Interstices between them are Filled Up in a Like Manner and the Dendrite is Completed.

and it will be considerably richer in the high melting-point constituent, that is, in the metal M, than the liquid from which it forms. Secondary and ternary axes will follow in turn *as the temperature of the alloy continues to fall* and these will contain more of the more fusible metal than the main axis but still less of it than the molten metal. Finally, the interstices between the axes will solidify and will contain more of the low melting point metal M′ than

the axes. In other words, the formation of a dendrite of a solid solution implies a gradual segregation of the low melting point constituent as the dendrite grows, the portion of last solidification being the richest in that constituent. The boundaries between adjoining crystalline growths, since they are the last to solidify, should contain more of the fusible constituent than any portion of the dendrites themselves. If the boundaries between the dendrites are occupied, as some believe, by amorphous metal or cement, it seems obvious that this amorphous material must be much richer in the low melting point metal than the original alloy. We lack

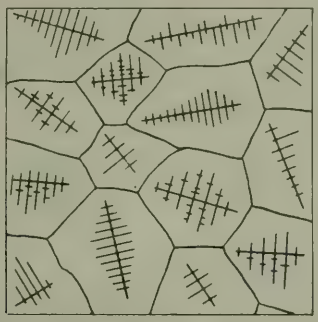


Fig. 13—Dendrites and Boundaries. (After Desch.) The External Shape will Necessarily be Influenced by Eventual Contact with Neighboring Dendritic Growths and Boundary Lines Should Exist Between Them.

experimental evidence, however, that this is actually the case. The mechanism of the formation of solid solutions, therefore, necessarily implies the production of chemically heterogeneous dendrites. The segregation producing this heterogeneity may be called *dendritic segregation.*

While this heterogeneous dendrite is in the process of formation, however, the phenomenon of diffusion asserts itself and tends to produce chemical homogeneity through the migration of some metal M from the parts in which it abounds to portions deficient in that constituent and in a like manner migration of some of the metal M′ from the fillings to the axes. This diffusion continues probably on cooling below solidification and is promoted by a slow solidification, long sojourn at high temperatures and slow cooling. Complete diffusion would efface altogether the dendritic segregation and a chemically homogeneous dendrite would be ob-

tained. It would then be impossible as previously explained to disclose by etching methods the dendritic crystallization since selective action could not take place. Impossibility of bringing out a dendritic structure in an iron or steel casting must be considered as an indication of a chemically pure metal or of a solid solution freed by diffusion from dendritic segregation. Dendritic segregation always occurs when a solid solution forms and complete diffusion is very rare. While diffusion may decrease to a considerable extent

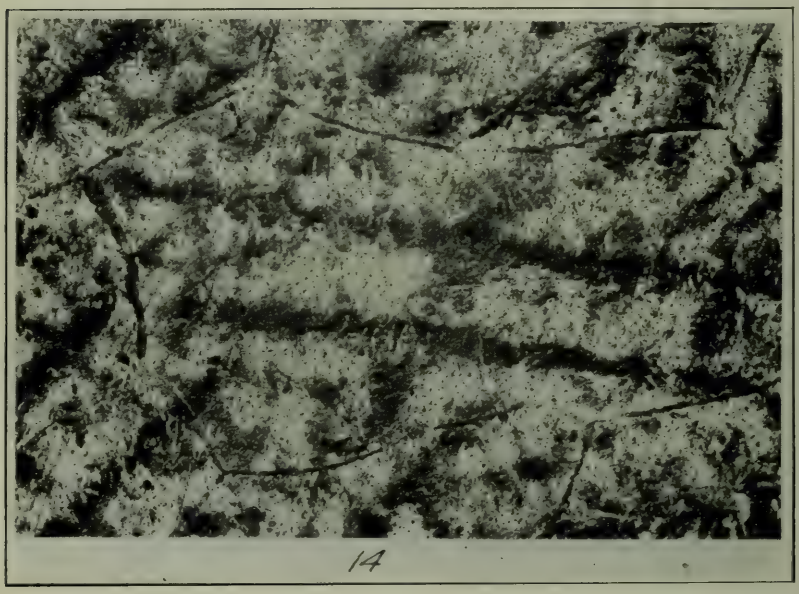


Fig. 14—Dendrites and Boundaries. ×74. (By V. N. Krivobok in the Author's Laboratory.)

dendritic segregation it does not efface it completely and the dendrites at room temperature remain chemically heterogeneous.

If the dendrites of a solid solution are chemically heterogeneous, that is, if their axes have a different chemical composition from the fillings, it becomes possible to bring out the dendritic structure through the selective action of suitable etching reagents. In the case of iron-carbon alloys, for instance, some copper etching reagents may cause a deposition of copper on the axes while the fillings remain unaffected, (Fig. 9).

Dendritic Segregation in Iron-Carbon Alloys

The fact that the dendritic structure of steel can generally be readily revealed by suitable etching treatments is an indication that the dendrites of steel are chemically heterogeneous, that is, that the dendritic segregation has not been completely eliminated by subsequent diffusion. It is important to know what constituents are chiefly responsible for this dendritic segregation. We may confine our attention to the three constituents which form with iron, solid solutions, namely, carbon, phosphorus and silicon. Stead claimed long ago that phosphorus was chiefly, if not altogether, responsible for dendritic segregation. This view was generally accepted and is still the prevailing one today.

According to Stead the main axes contain comparatively little phosphorus, the secondary and ternary axes a larger amount, and the fillings a still greater quantity. While diffusion may cause a decrease of phosphorus segregation, it cannot erase it and the dendrites at room temperature remain heterogeneous as to phosphorus distribution. On etching polished sections with some copper reagents, copper is deposited on the axes which are comparatively free from phosphorus, while it fails to be deposited on the fillings which contain considerably more phosphorus. Dendritic structure is in this way revealed. Stead claims further that phosphorus expels carbon from the portions of the dendrites where the former predominates into portions containing little phosphorus, that is, it expels carbon from the fillings and concentrates it in the axes.

The following experiment affords a striking confirmation of the claims that phosphorus produces persistent dendritic segregation and that in passing through the thermal critical range, carbon migrates from the portions rich in phosphorus, namely the fillings, to segregate in the axes, which contains relatively little phosphorus. Using armco iron, a steel ingot was prepared containing 0.17 per cent carbon and 0.39 per cent phosphorus. It was found that on etching this steel with the usual solution of nitric acid and alcohol, a very clear dendritic structure was revealed, (Fig. 15). Upon closer investigations, it was discovered that the axes were made of pearlite while the fillings, undoubtedly rich in phosphorus, were free from carbon (Figs. 16 and 17); hence the possibility of bringing out a dendritic structure by nitric acid etching. After

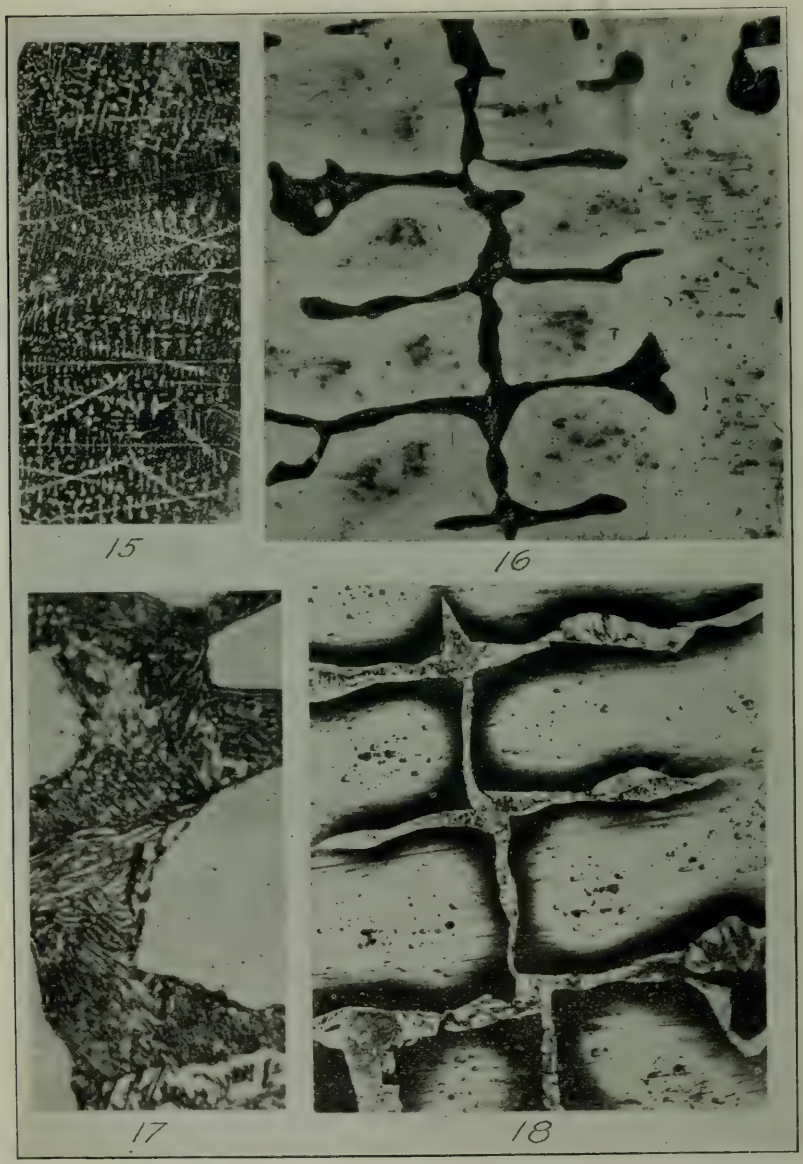


Fig. 15—Dendritic Segregations Revealed by Etching with Nitric Acid. ×4. FIG. 16—Same as Fig. 15. ×—65; Fig. 17—Same as Fig. 15. ×—1000. Figs. 16 and 17 Show that the Axes Were Made of Pearlite, while the Fillings Undoubtedly Rich in Phosphorus, Were Free from Carbon, Hence the Possibility of Bringing Out the Dendritic Structure by Nitric Acid Etching. Fig. 18—Same as Fig. 15. ×—85. Etched with LeChatelier Reagent. After treatment with LeChatelier Reagent a Similar Dendritic Structure is Obtained Through the Copper Being Deposited on the Phosphorus-free Ferrite of the Pearlite Axes. The Fillings Were not Affected. (Micrographs by V. D. Krivobok in author's laboratory.) Analysis; Carbon, 0.17 per cent, Phosphorus, 0.39 per cent.

treatment with the Le Chatelier reagent, a similar dendritic structure is obtained (Fig. 18) through the copper having deposited on the phosphorus-free ferrite plates of the pearlitic axes, while the impure ferrite constituting the fillings was not affected, except for the ferrite immediately surrounding the pearlitic axes where it is freer from phosphorus, thus producing an intense coring effect.

The conclusions seem warranted that, on solidifying, the phosphorus, by locating in the fillings of the dendrites, produced intense and peristent dendritic segregation and that on cooling through the thermal critical range, the phosphorus caused the carbon to leave the fillings and to collect in the axes resulting in pearlitic axes and ferrite fillings. While we have here a strong indication that phosphorus produces persistent dendritic segregation and that it is capable of expelling carbon from the regions where the former abounds, it would not be wise to infer that phosphorus alone is responsible for persistent dendritic segregation, because such segregation has been found repeatedly in steel practically free from phosphorus. We are led to inquire, therefore, what other elements besides phosphorus are capable of producing it.

Persistent dendritic segregation caused by phosphorus results, on working the steel, in the formation of ferrite bands or ghosts (the drawn fillings) rich in phosphorus and inclusions and in pearlitic bands (the drawn axes) as shown in Fig. 20.

Le Chatelier has challenged Stead's contention that persistent dendritic segregation in steel was always due to the presence of phosphorus. In his opinion oxygen is the element responsible for it. He finds that when steel containing phosphorus is melted in hydrogen and is therefore free or nearly free from oxygen, a dendritic structure cannot be brought out by etching, which indicates absence of dendritic segregation. On the other hand, steel free from phosphorus but melted with free access of air and therefore containing oxygen is found to be dendritic after etching. Additional experimental evidences are needed in order to strengthen or to disprove the accuracy of this contention.

Disregarding for the moment what element or elements are responsible for persistent dendritic segregation and therefore for the possibility of revealing by etching the dendritic character of the crystallization of steel, it may be considered as firmly established that after solidification all steels are composed of closely

interlocked dendrites (Fig. 9). If we refer to Fig. 19 in which the steel portion of the iron-carbon diagram has been reproduced, it will be noted that the dendrites formed as the alloy cools from its liquidus AB to its solidus ACD. In the complete absence of

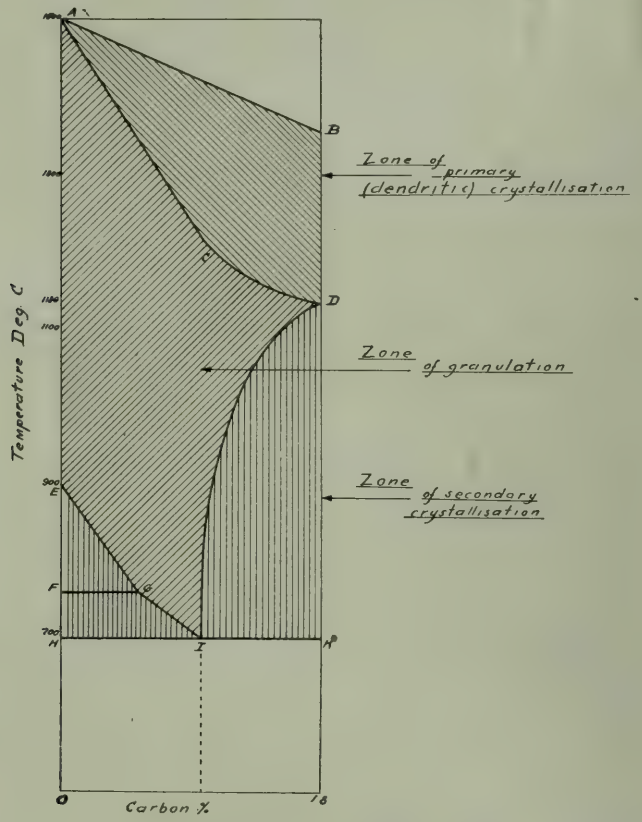


Fig. 19.—Steel Portion of the Iron-Carbon Equilibrium Diagram. It will be Noted that the Dendrites Form as the Alloy Cools from Its Liquidus AB to Its Solidus ACD. In the Complete Absence of Carbon these Dendrites Necessarily Form at a Constant Temperature, Namely at the Melting Point of Pure Iron. As the Carbon Increases the Distance Between Liquidus and Solidus Increases and Becomes Maximum at 1.00 per cent Carbon. From 1.00 to 1.80 per cent Carbon it Remains Practically the Same Length.

carbon these dendrites necessarily form at a constant temperature, namely, at the melting point of pure iron. As the carbon increases the distance between liquidus and solidus, that is, the solidification range, increases and becomes maximum at about

1.00 per cent carbon. From 1.00 to 1.80 per cent carbon it remains practically of the same length. The question may reasonably be asked whether the length of the solidification range has any influence on the size of the dendrites—whether a long range of solidification promotes the formation of more or of fewer dendrites; whether the number of dendrites in eutectoid steel, for instance, with its wide range of solidification is greater or less than the number of dendrites in hypo-eutectoid steel? While there is good ground for believing that the dendrites of eutectoid steel and of hyper-eutectoid steel are smaller than those of hypo-eutectoid steel doubt still exists as to whether this difference is due to differences in the solidification ranges of the steels or to differences in their carbon content.

Granulation of Dendrites

If the dendritic structure of steel resulting from solidification underwent no modification or transformation on further cooling, all steels at room temperature would consist of interlocked austenitic dendrites. Although their properties would undoubtedly vary somewhat with their carbon content and the size and form of the dendrites, they would possess the characteristics of the solid solution austenite. They would be very resistant to abrasion, very difficult to machine and they would be nonmagnetic. They would resemble Hadfield's manganese steel and would have a limited range of application.

On cooling from the solidus to room temperature, however, very important transformations occur which impart entirely new properties to the metal. When a sample of carbonless iron or of steel containing a very small amount of carbon is allowed to cool slowly from the liquid state to room temperature, it is found on microscopical examination, after etching with the usual reagents, to be made up of small polyhedral crystals or micrograins. If a little carbon is present, small particles of pearlite will also be formed. (Figs. 21 and 22).

From the foregoing description of the formation of dendrites and of macrograins on solidification it seems evident that these small micrograins must have formed after solidification; that they result from a breaking down of the dendrites. This theory, advanced by Belaiew gives us the only acceptable explanation of the relation between the microstructure of steel and its dendritic

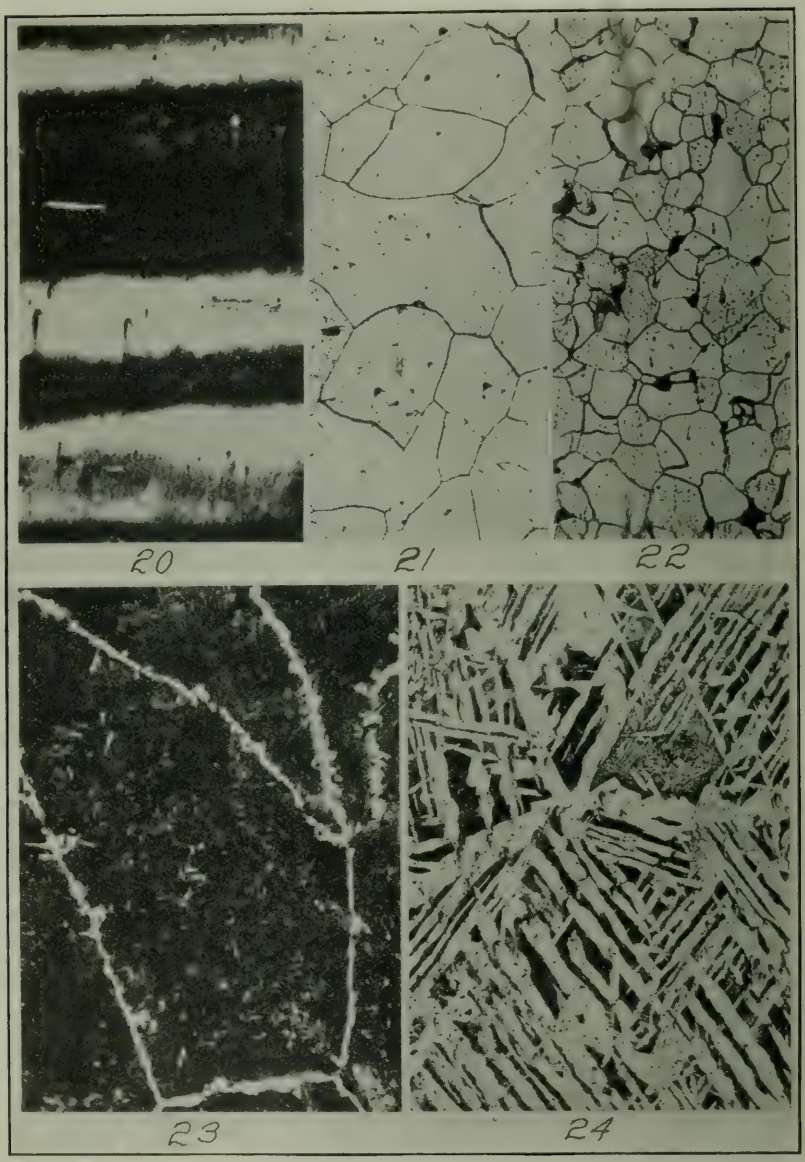


FIG. 20—Banded Structure in Rolled Steel Caused by Persistent Dendritic Phosphorus Segregation. ×—100. Fig. 21—Polyhedral Microstructure of Carbonless Iron ×—125. (By D. C. Lee in author's laboratory); Fig. 22—Polyhedral Microstructure of Low Carbon Steel. ×—100. (By E. L. Chao in author's laboratory); Fig. 23—Network Structure in Hypo-eutectoid Steel Casting. ×—65. Fig. 24—Cleavage Structure in Hypo-eutectoid Steel Casting, Showing the Well Known Widmanstatten Structure. Etched with Nitric Acid. ×—100. (Figs. 23 and 24 by V. D. Krivobok, in author's laboratory.)

structure, generally of macro size. Belaiew argues that when steel cools from the solidus to the thermal critical range the dendrites and the large grains constituted by the boundaries of those dendrites undergo a process of granulation. The granulation zone corresponds to the area ACDIGE of the equilibrium diagram (Fig. 19). In cooling through this zone each dendrite breaks up into a number of small (micro) grains, each having its own crystalline orientation. Since they form above the thermal critical range, they are austenitic micrograins. *Such a process necessarily implies the disappearance of the dendrite as a crystalline unit.* In other words, a large allotriomorphic crystal necessarily of constant crystalline orientation throughout has been transformed into a number of small allotriomorphic crystals every one with its own orientation and, therefore, independent crystalline existence.

An examination of the zone of granulation, that is, of the area ACDIGE, of the equilibrium diagram reveals the fact that the width of that zone varies greatly in different steel. For carbonless iron it extends from about 1500 to 900 degrees Cent., (2730 to 1690 degrees Fahr.), covering a range of 600 degrees Cent. (1110 degrees Fahr.). As the carbon increases the granulation zone decreases slightly. For eutectoid steel, it still covers a range of 500 degrees Cent. (930 degrees Fahr.) (from 1200 to 700 degrees Cent.) As the eutectoid point is passed, however, the granulation zone decreases very rapidly. With 1.50 per cent carbon it is reduced to 1.30 degrees Cent. (1130 to 1000 degrees Cent.) With 1.80 per cent carbon the granulation zone disappears. Hypo-eutectoid and eutectoid steels, therefore, have wide granulation zones (500 to 600 degrees Cent.), while in hyper-eutectoid steel the granulation zone is rapidly narrowed, being finally reduced to zero. It is pertinent to ask whether for like cooling conditions the extent of the granulation zone affects the number of the resulting grains; whether the grains of hypo-eutectoid steel should be for that reason more or less numerous than the grains resulting from the granulation of hyper-eutectoid steel. We naturally infer that the absence of a granulation range in steel containing 1.80 per cent carbon must signify that the dendrites of steel of that composition do not break up into independent crystalline grains.

The nature of the boundaries surrounding the micro-grains resulting from the crystallographic breaking up of the primary

dendrites should be considered. Rosenhain in formulating and explaining his amorphous cement theory contends that amorphous iron exists at the boundaries of the micrograins on the ground that they coincide with the last films of metal to solidify. If the granulation theory of Belaiew is correct, Rosenhain must be wrong, since these small grains were not formed during solidificaton but *below* solidification. Amorphous iron should exist at the boundaries surrounding the dendrites according to Rosenhain, but not, at least not for like reasons, at the boundaries between the micrograins. It might be argued that amorphous cement exists also at the boundaries between the micrograins on the ground that when a crystallographic form is transformed into another crystallographic form the substance must first assume the amorphous state and that this state is retained at the boundaries, the final amorphous films surrounding the grains being too thin to assume the crystalline orientation of either of the adjoining grains.

Seeing that the dendrites formed during solidification are entirely destroyed through the granulation they undergo between the solidus and the thermal critical range, it is at first a source of surprise that we should ever be able to bring out a dendritic structure in steel at room temperature. The answer to the apparent enigma is that *the possibility of revealing a dendritic structure through etching treatment does not depend upon the existence of dendrites but upon the existence of dendritic segregation and that while granulation obliterates the dendrites it does not affect dendritic segregation.* The segregating element, whatever it may be, occupies the same portions of the original dendrite even after the latter has undergone granulation. Treatment with the copper reagent, for instance, still results in a deposit of copper on those portions of the polished surface once occupied by dendritic axes since those portions are as free from the segregating element as they were before granulation. The result is a dendritic structure generally of macro-size brought out by suitable reagents and resulting from dendritic segregation and a micro-structure resulting from the granulation of the dendrites .

From the close examination of a great many samples treated with the Le Chatelier reagent the author reached the conclusion that *copper is deposited on ferrite only and that when both ferrite rich in the segregating element and ferrite poor in that element,*

for brevity of speech impure and pure ferrite, are present, it is on the pure ferrite only that copper is deposited. In the absence of ferrite, in austenitic and martensitic steels, for instance, it is quite impossible to develop a dendrtic structure by means of the Le Chatelier reagent. It does not follow, however, that dendritic segregation does not exist in these steels and that it cannot be revealed by other reagents or other treatments.

Secondary Crystallization and Microstructure

It has been shown that steel on cooling from the liquid state to its thermal critical range solidifies through the formation of many dendrites, that these dendrites undergo granulation on cooling below

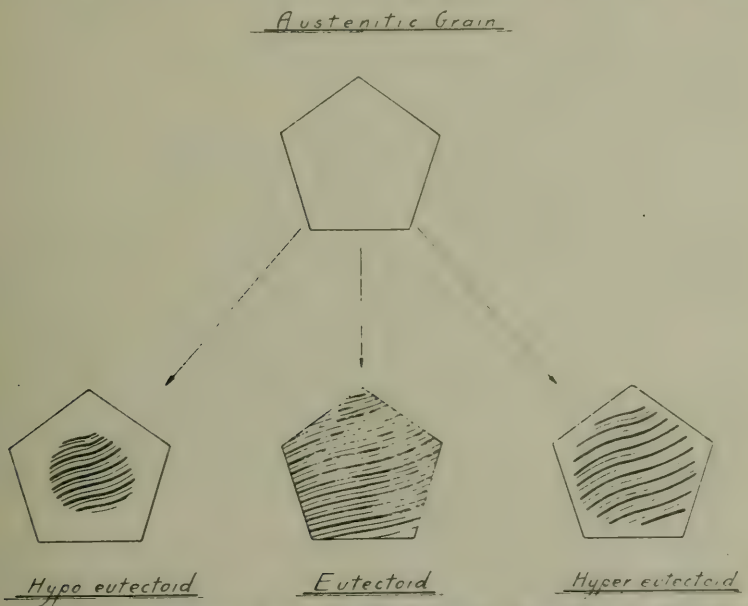


Fig. 25—Diagrammatic Sketch of the Austenitic Grain Passing Through Its Thermal Critical Range.

the solidus but that the dendritic segregation which necessarily accompanies the formation of solid solutions persists. On reaching the thermal critical range therefore all steels are made up of grains generally of micro-size resulting from the granulation of austenitic dendrites generally of macro-size, with the possible exception of steel containing 1.80 per cent carbon which has no granulation range.

We should now consider what takes place when the steel cools through its thermal critical range to room temperature. The mechanism of that transformation is well known. If the steel is of eutectoid composition such a grain of austenite is converted into a grain of pearlite at the single critical point of that steel. (Fig. 25). If the steel is hypo-eutectoid a certain amount of ferrite separates from the solid, austenitic solution on entering the critical range until the remaining austenite finally of eutectoid composition is transformed into pearlite at the bottom of the range that is at the Ar_1 point. If the steel is hyper-eutectoid, it is cementite which separates in a like fashion in cooling through the range. In Fig. 25 it has been assumed that the entire amount of ferrite or of cementite is rejected to the boundaries. It will soon be shown that some of the separating constituents may be retained in the cleavage planes of the grains.

When carbonless iron cools through its upper critical point, it passes from the gamma to the alpha condition* and since the cube is the crystallographic form of alpha iron while the octahedron is the crystallographic form of gamma iron it must be assumed that each grain undergoes at that temperature a crystallographic transformation. In hypo-eutectoid steel the ferrite which separates on entering the critical range and keeps on separating on cooling through the range, passes immediately from the gamma to the alpha condition and must therefore be made up of small cubic crystals. That alpha ferrite is made up of small cubic crystals can be readily revealed by suitable etching tests.

Belaiew calls the transformation taking place during the critical range, secondary crystallization.

The speed of cooling through the critical range has a marked effect upon the location and distribution of the separating constituent, ferrite or cementite, and therefore upon the final structure of the casting. Speeds of cooling sufficiently slow to permit complete separation of the excess ferrite or cementite and final transformation of the remaining austenite into pearlite are alone considered here. Bealiew believes that if the cooling through the range be extremely slow the separating constituent is given the necessary time to reach the boundaries of the crystalline grains and distinct network structures are obtained. (Fig. 23). If on the contrary the cooling is too rapid to permit this migration the separating element

*The author purposely disregards here the possibility of gamma iron transforming into beta iron, lest he draw the fire of the anti-beta contingent.

will be retained to a greater extent in the crystallographic planes of the octahedral crystals and the well known Widmanstätten or cleavage structure will result. (Fig. 24).

According to Belaiew a very slow cooling through the granulation zone promotes the formation of the Widmanstätten type of structure on quick cooling through the critical thermal range. In spite of Colonel Belaiew's brilliant defense of his conception of the formation of the Widmanstätten structure, it fails to fully satisfy. It is difficult at the outset to oppose his theory because he wins both ways. When the Widmanstätten structure is obtained after rapid cooling through the zone of secondary crystallization, it is in accordance with his conception, and when such structure results from slow cooling through the zone, it likewise conforms with his theory on the ground that it is then due to undercooling.

It is hardly necessary to insist on the fact that steel castings exhibiting the network structure cannot be expected to have properties identical to those of castings exhibiting the Widmanstätten structure, although identical in chemical composition. In the majority of cases steel castings exhibit a structure having some of the characteristics of both types, that is, in which the separating constituent is situated partly at the boundaries and partly at the cleavage planes. This may be called "mixte" structure.

It is not unreasonable to suppose that the size of the grains formed during granulation and which is probably dependent upon the size of the dendrites may influence the final structure, that is, may induce or oppose the network type of structure or the Widmanstätten type. Will a large austentitic grain for instance result in a Widmanstätten structure more readily than a smaller grain of the same steel? Seeing that in a large grain the separating constituent has a longer way to travel to reach the boundary, it seems that this might be the case. Assuming this reasoning to be sound, Widmanstätten structures should form more readily in hypo-eutectoid than in hyper-eutectoid steels, since the former for like cooling conditions have larger grains.

Many queries of a practical nature come to mind. Will a network structure respond to the annealing treatment more readily than the Widmanstätten structure and should it therefore be promoted in our castings? It is not likely that both behave in a similar manner; one must be preferable and should be induced and

while one type might be more advantageous in castings that are not to be annealed, the other type may be more desirable in castings to be annealed. This opens up an important field of investigation.

In high carbon steel the zone of granulation is very narrow and when the metal contains 1.80 per cent carbon it is non-existent, (Fig. 19). High carbon steels, therefore, should have very small austenitic grain on reaching their critical range ID, (Fig. 19). While it would seem as if this must result in the separating cementite readily reaching the boundaries and forming network structures, Belaiew believes that in such high carbon steel the cementite has a tendency to separate parallel to the crystallographic axes of the dendrites, giving rise to structures that he calls "large crystals." In the extreme case of an alloy containing 1.80 per cent carbon, since the metal does not granulate at all, as soon as it has solidified, (D, Fig. 19), cementite begins to be rejected by the cooling dendrite and locates itself along the crystallographic axes of that dendrite.

To further clarify and sum up the foregoing discussion let us follow the solidification and cooling to room temperature of carbonless iron, hypo-eutectoid steel, eutectoid steel, hyper-eutectoid steel and steel containing 1.80 per cent carbon.

Solidification of Carbonless Iron

Carbonless iron solidifies at 1530 degrees Cent. (2785 degrees Fahr.) when dendrites of gamma iron* are formed. The dimensions of the dendrites probably depend on the rate of cooling, a rapid solidification causing the appearance of a greater number of nuclei and therefore of smaller dendrites. If the iron contains some impurity subject to persistent dendritic segregation, chemically heterogeneous dendrites will result and their detection will be possible at room temperature through the selective action of a suitable reagent. If it does not contain such impurities, the dendrites will be chemically homogeneous and it will not be possible to reveal by etching the dendritic character of the solidification of the metal. Accepting Rosenhain's theory, the boundaries tretween adjoining dendritic growths should be occupied by amorto rus iron. In cooling from the solidification point to 900 deworks Cent. (1690 degrees Fahr.) every dendrite breaks up into

coo[1]

*The author intentionally ignores the possibility of the dendrites consisting of delta —on before granu'ation and of gamma iron after granulation.

small (micro) grains of gamma iron. The number and, therefore, dimensions of these grains probably depend upon the rate of cooling through the granulation zone and on the size of the dendrites which in turn depends upon the rate of solidification. On reaching the upper critical point of pure iron, at about 900 degrees Cent. (1690 degrees Fahr.), each grain of gamma iron is converted into a grain of beta iron, or according to those who deny the existence of beta iron, into a grain of alpha iron, accompanied by a transformation of the octahedral units of gamma iron into the cubic units of alpha iron.

At room temperature, carbonless iron consists of a mass of polyhedral micro-grains of alpha iron which have been formed *in situ* at the point Ar_3 through the transformation of as many grains of gamma iron, themselves formed, during the granulation zone through the crystallographic breaking up of the dendrites resulting from solidification. If persistent dendritic segregation exists treatment with the Le Chatelier reagent will result in copper being deposited on the ferrite of the axes because it contains less of the segregated element or elements than the ferrite of the fillings. In this way, although the dendrites themselves no longer exist, the dendritic character of the crystallization of iron stands revealed.

Solidification of Hypo-eutectoid Steel

Let us now follow the solidification and cooling to room temperature of a hypo-eutectoid steel. Let us assume that it contains 0.50 per cent carbon. The solidification of such steel will begin at about 1475 degrees Cent. (2685 degrees Fahr.) and will be complete at 1300 degrees Cent. (2370 degrees Fahr.), Fig. 19). It will proceed, therefore, as the temperature is falling and will cover a range of some 175 degrees Cent. (345 degrees Fahr.). Crystallization starts at many centers or nuclei and dendrites are formed, their number and size depending on the speed of solidification, a greater speed probably inducing a greater number of nuclei and, therefore, a greater number of dendrites necessarily of smaller size. These dendrites consist of a solid solution of carbon in gamma iron, that is, of austenite In cooling through the granulation zone which extends from 1300 to 750 degrees Cent. (2370-1380 degrees Fahr.), these austenitic dendrites generally of macro-size are converted into small micro-grains of austenite, each one with its own orientation and, therefore,

independent crystalline existence. The number of these grains and, consequently, their size likewise will depend upon the size of the original dendrites and the rate of cooling through the granulation zone. It seems reasonable to assume that a rapid cooling through the zone of granulation will induce the formation of a greater number of grains necessarily of smaller dimensions. At a temperature of about 750 degrees Cent. (1380 degrees Fahr.,) the steel now composed of many austenitic grains of micro-size enters its critical range which, following Belaiew, we may call zone of secondary crystallization. At about 690 degrees Cent. (1275 degrees Fahr.) it emerges from that zone transformed into an aggregate of ferrite and cementite. As previously explained and according to Belaiew, if the cooling through that range has been sufficiently slow, a network structure will result, whereas a faster cooling tends to produce the Widmanstätten type of structure or a combination of both types which we may call "mixte" structure. If the grains formed in the granulation zone are large, a Widmanstätten structure should be produced more readily because of the greater distance to be covered by the separating ferrite in reaching the boundaries in order to form network structures and a slow cooling through the granulation zone should promote the formation of large austenitic grains.

If the dendritic segregation which necessarily accompanies the formation of solid solutions has persisted, a treatment with the Le Chatelier reagent will cause a deposition of copper on the free ferrite present in the axes as well as upon the ferrite plates of the pearlite in these axes, while the free ferrite and the pearlite-ferrite occupying the fillings will not be coated. This is in conformity with the belief previously expressed that copper deposits only on ferrite and that when both pure and impure ferrite are present, it deposits selectively on the pure ferrite and not on the impure ferrite. It follows that although the dendrites no longer exist at room temperature, the presence of dendritic segregation makes it possible to reveal the fact that on solidifying, the steel crystallized in the form of dendrites.

Solidification of Hyper-Eutectoid Steel

Let us now consider a hyper-eutectoid steel containing 1.5

per cent carbon. It solidifies on cooling from 1400 to 1150 degrees Cent. (2750-2100 degrees Fahr.) It is then made up of austenitic dendrites, the number and dimensions of which will depend upon the rate of solidification as previously explained. The granulation zone of this steel extends from 1150 to 1050 degrees Cent. (2100-1920 degrees Fahr.), and in passing through it, each dendrite breaks up into a number of austenitic grains, generally of micro-size, a fast cooling probably inducing the formation of a greater number of grains and consequently decreasing their size. At 1050 degrees Cent. (1920 degrees Fahr.) the steel enters its thermal critical range or range of secondary crystallization. At the point Ar_1 about 690 degrees Cent. (1275 degrees Fahr.) it emerges from that range converted into an aggregate of pearlite and cementite, the network type of structure being promoted by slow cooling through that range, and the Widmanstätten type by fast cooling. In view of their short granulation zone, hypereutectoid steels should be made up of smaller austenitic grains, for like cooling conditions, on reaching their thermal critical range, than hypo-eutectoid steels, and this is known to be so.

If the dendritic segregation which necessarily accompanied the solidification of the steel has persisted, it will be possible by treatment with the Le Chatelier reagent to reveal the dendritic character of that solidification, although the dendrites themselves no longer exist. Copper will be deposited on the ferrite plates of the pearlite present in the axes because of their greater freedom from the segregated element, while it will not be deposited on the ferrite plates of the pearlite in the fillings, owing to their impurity. Copper will not deposit on cementite either in the axes or in the fillings. A dendritic structure is thus revealed.

Steel containing 1.80 per cent carbon should not undergo granulation since it enters its zone of secondary crystallization as soon as it has solidified. Belaiew believes that the separating cementite will then be located along the crystallographic axes resulting in what he calls "structure of large crystals." As the revelation of a dendritic pattern depends solely on persistent dendritic segregation, being independent of the location of the separating constituent, treatment with the Le Chatelier reagent should bring it out by depositing copper on the ferrite plates of the

pearlite present in the axes and not on the ferrite plates of the pearlite of the fillings.

Influence of Heat Treatment on Microstructure

The influence of heat treatment on the microstructure and on the dendritic segregation of steel will now be briefly considered. Let it be stated at the start that while a prolonged heating at a

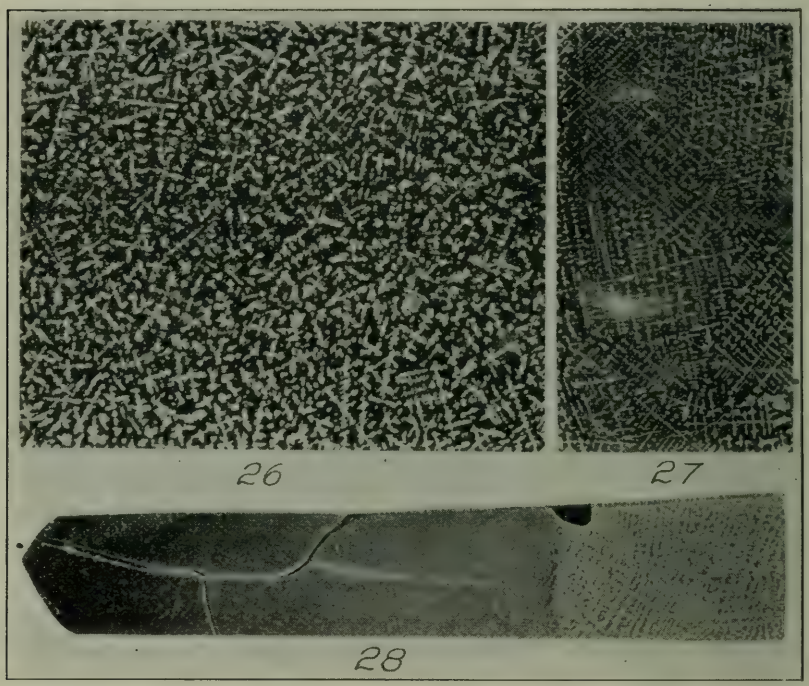


Fig. 26—Dendritic Segregation in Pearlitic Steel Annealed from 1500 degrees Fahr. ×—3. Etched with LeChatelier Reagent. (V. N. Krivobok in author's laboratory); Fig. 27—Dendritic Segregation in Sorbitic Steel. ×—1¼. Fig. 28—Dendritic Segregation in Troostitic Regions of a Quenched Steel. Etched with LeChatelier Reagent. ×—2. (R. F. Smith in author's laboratory.)

high temperature may induce diffusion and, therefore, decrease if not obliterate dendritic segregation, the commercial heat treatments are seldom of such character as to cause much diffusion. It is for this reason that after such treatments, it is generally found that the dendritic structure can still be brought out by suitable treatment. Dendritic segregation still persists. If the heat treatment results in pearlitic steel, the ferrite plates of the pearlite

in the axes as well as any free ferrite which may be present in the axes will be plated with copper while the ferrite in the filling will not, (Fig. 26). If the heat treatment results in sorbitic steel, copper will be deposited on the minute particles of ferrite present in the sorbite of the axes. (Fig. 27).

Fig. 28 shows strikingly the action of the Le Chatelier reagent in bringing out a dendritic pattern in troostitic areas while it fails to affect the martensitic portion of the same sample. This is further illustrated in Figs. 29 and 30, where the same spot of

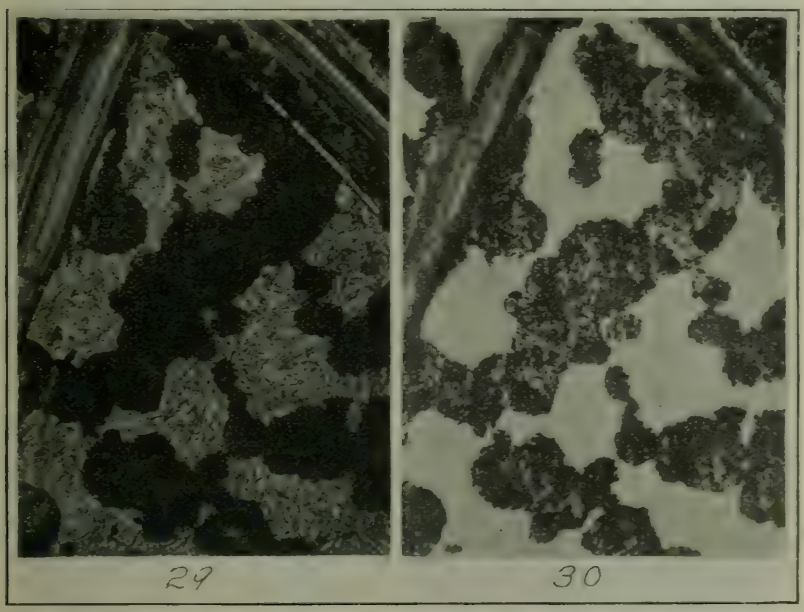


Fig. 29.—Quenched Hypo-eutectoid Steel Etched with Nitric Acid. ×—500. Fig. 30—Same Spot of Specimen as Fig. 29 Etched with LeChatelier Reagent. ×—500. Copper has Deposited on the Ferrite Particles Present in Troostite Imparting a Mottled Appearance to the Constituent, while the Martensitic Matrix Remains White and Brilliant. (R. F. Smith in the author's laboratory.)

a quenched hypo-eutectoid steel casting has been etched with dilute nitric acid and also with the Le Chatelier reagent. Copper has deposited on the ferrite particles present in troostite, imparting a mottled appearance to that constituent, while the martensitic matrix remains white and brilliant.

The fact that a dendritic structure may often be brought out in a steel made troostitic by heat treatment when etched by the

Le Chatelier reagent is, in the author's opinion, an indication that minute particles of ferrite are present in troostite; in other words, that that constituent is of the nature of an aggregate. Steel made martensitic or austensitic by heat treatment does not exhibit a

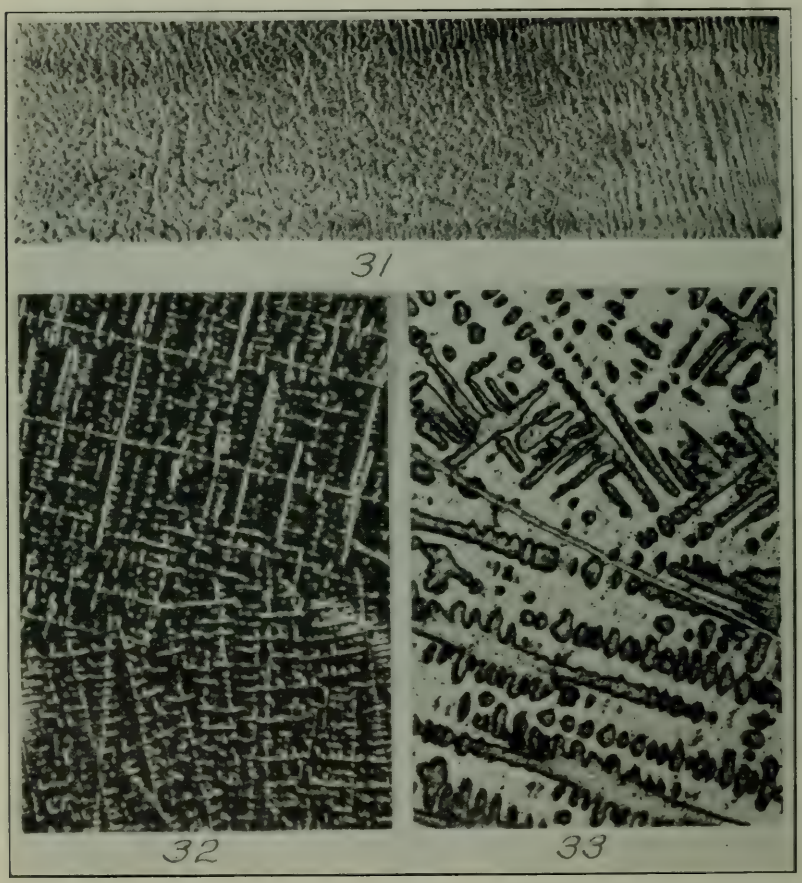


Fig. 31—Dendritic Segregation in Martensitic Steel Etched with Tincture of Iodine. ×—2. Fig. 32—Dendritic Segregation in Austenitic (Manganese) Steel Etched with Tincture of Iodine. ×—22. Fig. 33—Dendritic Segregation in Austenitic (nickel) Steel Etched with Ferric Chloride. ×—60. (Photomicrographs by V. D. Krivobok in the author's laboratory.)

dendritic structure when treated with the Le Chatelier reagent. This is because it does not contain ferrite and it is on ferrite only that copper is deposited. It does not follow that in such steel,

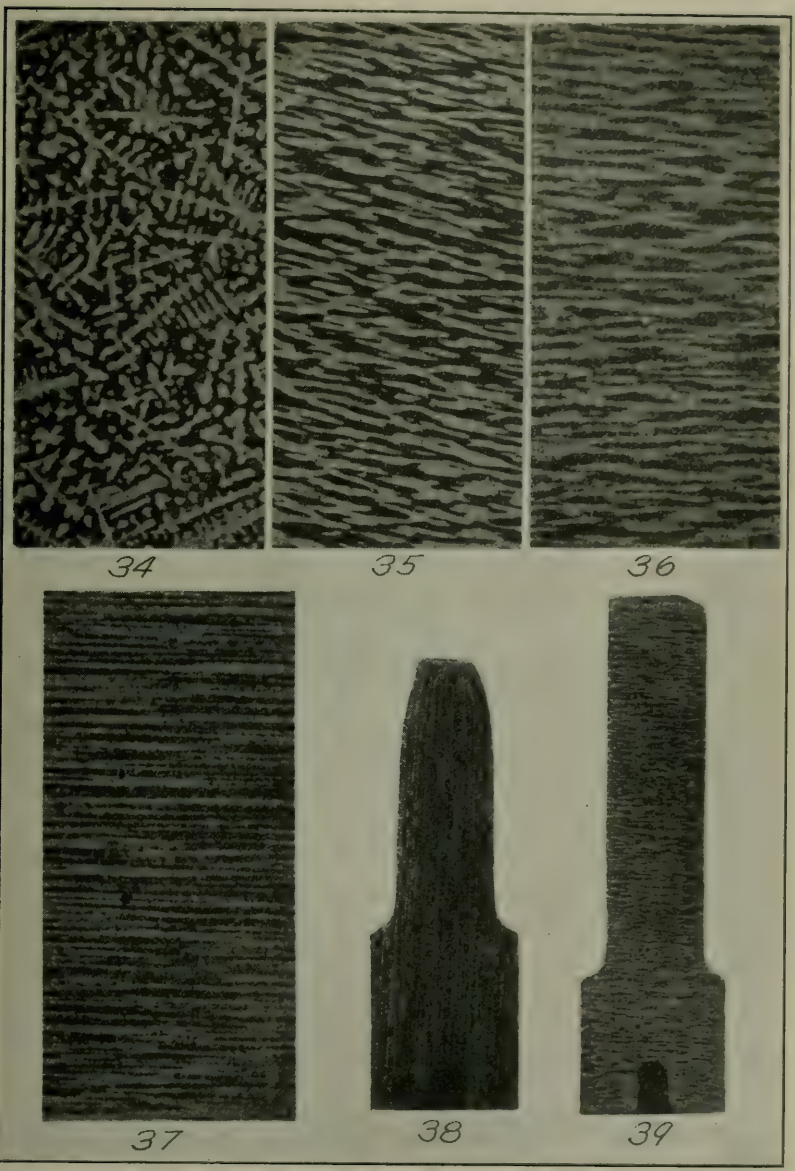


Fig. 34—Dendritic Structure in Cast Steel Ingot; Fig. 35—Same as Fig. 34 after Being Reduced 1/5 its Original Cross-section by Hot Working; Fig. 36—Same as Fig. 34 after being Reduced to 1/30 its Original Cross-section by Hot Working; Fig. 37—Same as Fig. 34 Reduced 1/150 its Original Cross-section by Hot Working; Figs. 38 and 39—Dendritic Segregation in Longitudinal and Transverse Tensile Test Bars. (After Charpy.)

dendritic segregation no longer exists. It merely indicates that the Le Chatelier reagent is now ineffective. Other treatments must be applied. Indeed, the existence of dendritic segregation in martensitic and austensitic steels may be brought out by etching with other reagents, (Figs. 31, 32, 33).

Influence of Work on Dendritic Segregation

If we now turn to the influence of work on dendritic segregation, we naturally find that the portions rich in the segregating elements (the fillings of the dendrites) as well as those poor in these elements, (the axes) are elongated in the direction of the work, imparting to the hot worked steel the well known laminated appearance readily revealed by macro-etching, (Figs. 34-37.) The steel seems to be composed of parallel bands. Some of these bands contain much of the segregating elements while others are quite free from them. The Le Chatelier reagent deposits copper on the latter while the former remain little, if at all, affected. Directional properties are in this way imparted to steel by hot working. The tensile strength, elastic limit and especially the ductility will vary much in accordance with the direction of testing, whether it is in a direction parallel to that of the work, at right angles with it, or in some other direction. In the absence of persistent dendritic segregation such structural orientation should not result from hot working and the metal should not acquire directional properties. Indeed the author is not aware that directional properties can be imparted to chemically pure iron by hot work. Obviously, the more pronounced and persistent the dendritic segregation, the more pronounced the directional properties. The directional properties resulting from hot working, combined with dendritic segregation is further illustrated in Figs. 38 and 39. The test bars were cut respectively in the direction of the work and at right angles. The much greater ductility of the former bar is clearly seen.

Conclusion

From the foregoing, and leaving out of consideration, the chemical composition and the presence of inclusions, it seems reasonable to assume that the physical properties of steel depend (a) upon its microstructure and (b) upon its persistent dendritic segregation. The influence of the microstructure has been ex-

haustively studied, but that of the dendritic segregation has been much neglected; indeed there are many who do not even suspect its existence. This paper is a plea for the study of that influence.

Persistent dendritic segregation is always harmful and should, if possible, be prevented or reduced. There seems, however, but two ways of eliminating it, to wit, by the absence of segregating elements, or by diffusion so complete as to cause the dendrites to become chemically homogeneous. In dealing with the first of these, we at once face a difficulty resulting from our ignorance of the elements responsible for persistent dendritic segregation. If, as Le Chatelier believes, oxygen is that element, we must of necessity always encounter some dendritic segregation since it is not a practical operation to melt our steels in vacuum. We may, however, lessen it by reducing, as much as it lies in our power, the oxidation of our steel. Well made electric steel and crucible steel as well as armco ingot iron should in that respect be superior to the product of other steel furnaces. If on the other hand, following Stead, phosphorus, is the chief cause of persistent dendritic segregation, there seems to be little to be done to prevent it as the steel of good quality at present manufactured is as low in phosphorus as is practical to make it.

In regard to the second means of preventing persistent dendritic segregation, namely by promoting complete diffusion of the segregated elements, it must be admitted that the ordinary heat treatments fail to accomplish this, although they may in some degree diminish segregation. Very slow solidification should help. Very long exposure to high temperature or repeated heating and cooling through the critical range would not be, in the majority of cases, a permissible operation.

Admitting the impossibility of completely preventing persistent dendritic segregation, we should recognize its existence and use all possible means for minimizing its harmful influence. We should endeavor to produce in our finished castings dendrites as small as possible and as free from persistent dendritic segregation as possible by suitably regulating the casting temperature and solidification conditions. We should regulate the cooling through the granulation zone, between the solidus and the ther-

Concluded on Page 83

HIGH-BROW VERSUS LOW-BROW

By Walter M. Mitchell

THERE is a very prevalent idea among many of those engaged in the noble art of heat treating that the only means of becoming proficient in this art is through practical experience, or by practical talks given by shopmen; and further, that no one really knows anything about the subject but the man in front of the furnace. The High-brow, who works in the laboratory, and publishes a technical paper about some obscure atom or molecule which he has caught by the hind legs, cannot, and does not know anything about heat treatment, and if placed between a furnace and a quenching tank at $40 per, would soon loose his job. Perhaps so—and yet perhaps not. The man who gives a practical talk, or writes a practical paper, gives other men, who are working with the same kind of equipment and on the same class of work, information which will be useful to them, but it may not be useful to anyone else. A practical talk on hardening razor-blades by a man in Hoboken will not necessarily benefit some man in Kansas City who wants to temper fishhooks. The practical talk tells us *what* to do, but not *why* to do it, and that is what the heat treater should know.

The High-brow, who makes investigations in the laboratory, studies the changes that take place in the constitution and structure of steel, and so learns what happens to a piece of steel when he hardens it, or when he anneals it, or why it will need normalizing. The technical paper which he writes explains some phase of what the heat treater is trying to do, and the man who knows what he is trying to do; i. e., who understands what changes he must bring about in the structure of the steel in order that it will have the properties that are desired when he gets through with it, is far better equipped for success with any kind of steel than is the man who knows only that if he does certain things at certain times a more or less certain result will follow. The latter method of heat treating is like the method of the man with the famous clock. It always kept splendid time—every time that the hands pointed to two and it struck seven he knew that it was three in the afternoon; but unfortunately this did not help

The author, Walter M. Mitchell, is consulting metallurgist, Philadelphia, Pa.

him when the hands pointed to five and it struck twelve, as it sometimes did. In that case he always blamed it on the stock room and said they had sent up the wrong kind of steel.

There is a certain steel works, which is probably only one of a dozen like it, and which for obvious reasons must be nameless, where a large portion of the output is heavy forgings of carbon and alloy steel. The carbon forgings are annealed, the alloy steel quenched and tempered—the specifications equivalent to those of the A. S. T. M. for the same class of material. This plant has an excellent microscope, recently purchased. There are two men in the organization who really know something of metallography, and that martensite is not a new explosive, or pearlite a substitute material for 10-cent store jewelry. These men are not directly in control of the heat treating department. During five months association with this works, the writer has never seen either the superintendent of the heat treating department, or his assistant, using the microscope. They appear to regard it as a nice piece of apparatus, but entirely without practical use in heat treatment. The statistics for heat treating various lots of these forgings, a part of the regular output, are as follows:

	Passed specification	Failed and ordered reannealed	Percentage reanneal to total
Annealed 45 per cent Carbon Steel Forgings			
1st anneal	64	37	36.5
2nd anneal	17	12	41.0
Heat Treated Alloy Steel Forgings			
1st treatment	83	33	29.0
2nd treatment	20	10	33.3

This shows that there were 130 lots of carbon steel forgings annealed, of which only 81 lots passed specifications; while with the alloy steel forgings, 146 lots were treated, of which only 103 lots passed. In other words this department was treating nearly 50 per cent more steel than it produced, and consequently was costing the company very much more than it should.

Another plant during the early stages of the world war had a large contract for forgings of 3.5 per cent nickel, 2.25 per cent chromium steel, weighing about 1400 pounds each. When work commenced on these forgings reanneals ran between 16 and 18 per cent a week. The management, which was very High-brow, studied long and carefully to eliminate the cause of this

large percentage of retreatment, with the result that reanneals were eventually reduced to less than 3 per cent, and were maintained at that figure for weeks at a time—even under such a severe test as the microscopic examination of two specimens from each forging. Expensive? Yes—perhaps—but certainly not as expensive in the long run as treating half again as many tons of steel as are produced.

It is not to be supposed that the number of retreatments at the first plant can ever be reduced to the low average established at the second plant, because the forgings at this plant were uniform in size—a condition most favorable to success. But it is believed that a very material reduction in such retreatments would result if proper control were secured through careful microscopic examination of the forgings before and after annealing.

Heat treating deals with the processes and laws of Nature. But many heat treaters do not realize or stop to think that Nature is always right and never misses a trick, and cannot be fooled by any short-cut methods. Successful heat treating is not easy to accomplish, it can only follow when we understand what we are trying to do, and plan operations so that these same laws of Nature will have full opportunity to act. Nothing ever happens by chance, there is always some cause preceding it; but the cause may be, and frequently is, so obscured that we do not recognize it. When a heat treatment goes wrong there is *always* a reason *why*. This reason may not be easy to identify and frequently appears not to exist at all, but nevertheless does exist. Sometimes the cause of failure is under our control, or again it is not, but the most vital preliminary to success is to prevent that combination of circumstances which produced failure if such is possible; or if not, to alter procedure and conditions so that the elements which are not under control are largely eliminated.

The function of the High-brow, through careful investigations and researches, is to discover the natural laws that control the operations of heat treatment and the constitutional changes that necessarily must be produced in steel, so that we know and understand *why* a certain procedure must be followed. The Low-brow, on the other hand, with many years of practical experience gained by the observation of facts and conditions that cannot conveniently be reduced to mathematical formulae, tells us *how*

to do it. In this way both have their part to play and we cannot dispense with, or depreciate, either one.

Many years ago the hardening of steel, or what we now call "heat treatment," was a mysterious and almost sacred art, to be trasmitted only from father to son, or to some favored apprentice, rigidly bound to secrecy. All sorts of magical formulæ and concoctions were used and regarded as essential in the prevention of failure—the famous red-haired boy and the fat negro slave, for instance. But the High-brow, through intimacy with solid solutions, allotropic transformations, eutectics, etc., has dispersed this fog of medievalism so that heat treatment is no longer a subject of dark mystery and incantation. Many of the High-brow investigations appear to be without practical value, but no one can predict what ultimate benefit may result. A few years ago tungsten was regarded as a laboratory curiosity, its discovery a scientific stunt; yet this same laboratory curiosity has revolutionized machine shop practice throughout the world, and in replacing the inefficient carbon filament of the incandescent lamp has many times repaid the cost of the seemingly impractical investigations. Vanadium, one of the rarer metals, was for a long time of interest to astronomers only, as a prominent constituent of sun-spots, shown by the spectroscope; while today it is a vitally important ingredient of high grade steels. Many similar illustrations might be given, but they would all point to the same truth. They are a direct result of the High-brow laboratory investigations which are sometimes so freely criticized and disparaged.

There is a vast field of metallurgy yet to be discovered, the knowledge of which must ultimately be of greatest usefulness. So far we have barely "etched" the surface. Most of the explorations in this unknown land will be made by the High-brow investigator working in the laboratory on things which to the man in the shop—and alas, too often to the executive—seem to be of no practical use. Let us by all means encourage such investigations that we may ultimately profit by the results obtained. The technical papers and discussions are really prepared for our enlightenment and education, if we can but see it that way. And education is the basis upon which the American Society for Steel Treating was founded—but there are many of us who do not know how badly we need it.

FORGING AND HEAT TREATING LARGE SECTIONS

By W. R. Klinkicht

Abstract

This paper describes the routine operations which are used in the forging and heat treating large section, as practiced in a modern heavy forging plant, equipped with suitable cranes, manipulating devices and heating equipment. Figures illustrating the operations of the annealing, forging and subsequent heat treating are included.

Introduction

IN VIEW of the wonderful strides made in the past few years in methods and equipment for forging and heat treating, it is interesting to pause for a moment and consider how our ancestors handled their problems in the working of iron and steel, which we know is one of the oldest of arts. We find many references to the art in the Bible where Tubal Cain is referred to as an "instructor of every artificer in brass and iron."

Very little is known of the early smiths, or their methods, however, the illustration Fig. 1 gives as reliable an idea as can be found. A fire was built in a depressed place in the ground, a forced draft being given to the flame by an attendant on either side who worked bellows by standing on them, alternately throwing their weight from one foot to the other and pulling up the bellows with ropes as the weight was shifted, thus permitting the instruments to be emptied and filled alternately. It is interesting to note that the method of forcing a fire by means of bellows was used probably 4,000 years ago.

There seems to have been very little improvement made in the working of iron and steel for many centuries, until the stack furnace and then the Catalan forge and other advances took place, but it was not until the sixteenth century that any attempt was made to apply mechanical instruments in the forging operation. We are told that about the year 1550 the trip hammer, operated by means of a waterwheel, constituted the first attempt at mechanical forging equipment.

A Swedish application of the waterwheel method is shown in

A paper presented before the Cincinnati chapter of the Society. The author, W. R. Klinkicht is connected with the Pollak Steel Co., Cincinnati, Ohio.

Fig. 2 wherein three hammers are shown in operation in addition to the bellows arrangement for smelting and forging. If we are to judge from the illustration, this smith was a busy man, there being bars under all three hammers, in addition to the one he is holding in the heating furnace.

As the demand for wrought iron forgings increased it became necessary to obtain a force of impact greater than could be

Fig. 1.—An Old Sketch Showing Early Smiths at Work Using Primitive Forced Draft Fires.

supplied by human muscles or the methods then in use, so the idea was conceived of attaching a heavy slab of iron to a rope, then lifting it in vertical guides with a gang of men and dropping it from any desired height within the capacity of the machine. This contrivance was called the Hercules and was a fairly efficient tool for that period.

The eighteenth century witnessed the introduction of the lift and tilt or helve hammer, operated first by water-wheels and later by steam. A waterwheel tail hammer of this period is reputed to be in operation today in Sheffield, England. When we consider the class of work turned out with this equipment, we may well marvel at the handicraft of these artisans.

James Watt appears to have been the originator of the first steam hammer and it was patented by him in 1784. However, no steam hammers appear to have been made under his patent and in 1839 James Nasmyth of the Bridgewater Foundry, near Manchester, England, designed and patented a steam drop hammer. This hammer was designed because of an appeal to Mr. Nasmyth, by a Mr. Humphries of the Great Western company, who wished a large paddle shaft forged for a new steamship then under construction. After making a survey of the forge shops in the country it was found that none were able to undertake the forging of

this shaft because of the lack of proper equipment, so the construction of the first steam drop hammer was begun, Fig. 3. The method of the propulsion of the boat was later changed to the screw propeller type so the shaft was not needed and the

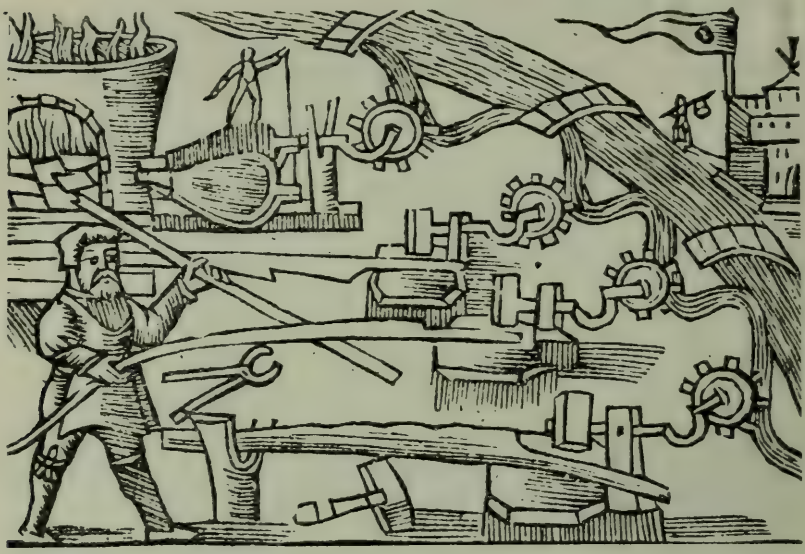


Fig. 2.—A Swedish Application of the Waterwheel for Driving Hammers.

hammer was not completed until four years later. From that time on rapid strides have been made in hammer development and with this development came the hydraulic and steam press.

Pressed Forgings

Forgings made under a press are unquestionably of superior quality due to the deeper and more uniform penetration characteristic of press performance. This point is clearly emphasized in the convexed ends of pressed forgings, and borne out by physical and microscopic tests.

Forgings pressed directly from ingots have shown better physical properties than those forged from blooms because of the more accurate control of temperature and the superiority of pressing over rolling. But, before forging an ingot it is necessary that important points be considered. Most forgings are ordered to specifications calling for certain chemical composition and physical characteristics. The chemical composition having been de-

termined by analyzing drillings taken from various points on the ingot, the weight of the forging as compared with the ingot weight is next to be considered. An allowance of about thirty percent of the total weight of the ingot must be made for

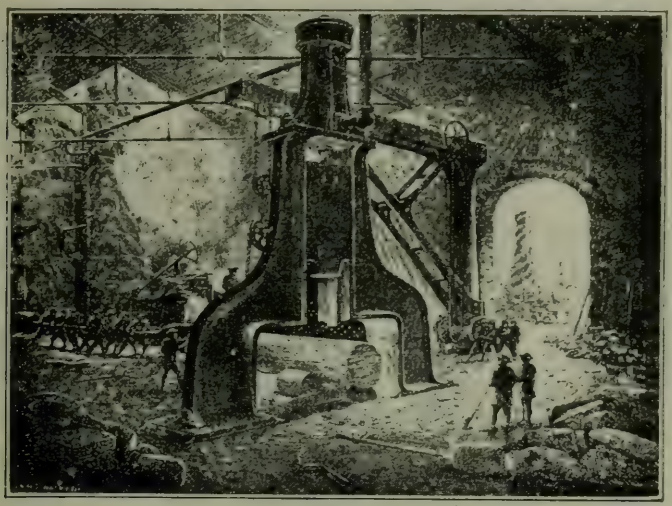


Fig. 3.—First Steam Drop Hammer.
(From Autobiography of James Nasmyth)

discard and the area sufficiently large to permit of a reduction of about four to one. The ratio of reduction is usually greater.

Heating

The heating of ingots for forging is an operation requiring great care. Too rapid heating will cause a rapid expansion of the outside which will cause it to draw away from the interior, resulting in cracks and cavities and for this reason they must be carefully preheated. At the same time a slightly reducing atmosphere must be maintained to prevent excessive decarburization of the surface during the many hours required to thoroughly heat the steel. It has been truthfully said that the real heat treatment of steel begins with the heating for forging and the factors time, temperature and area are as applicable to the forging as well as the heat treating operation. The need of thoroughly trained heaters, properly supervised, is readily apparent.

Time Required for Heating

To accurately determine the actual time required to heat large ingots, tests were made with full size sections by drilling a hole midway into the ingot, inserting a thermocouple carefully wrapped with asbestos and packed around the outside to prevent entrance

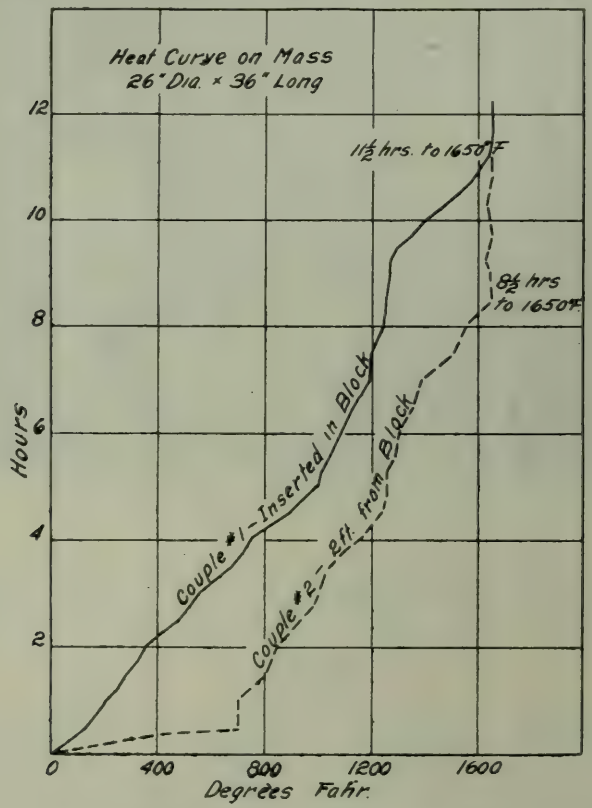


Fig. 4.—Curves Plotted from Results Obtained in Heating a Section 26 Inches in Diameter and Bears out the Generally Approved Statement that One Hour Heating for each Inch of Section is Satisfactory.

of heat. Another couple was then placed in the furnace about two feet away from the steel and the temperatures periodically checked and recorded. The curves in Fig. 4 were plotted from the results obtained in heating a section 26 inches in diameter and bears out the generally approved rule, that about one hour

heating for each inch of cross section is satisfactory. The critical range of the steel is also clearly shown in this chart.

Pressing

After the ingot has been thoroughly heated at the proper

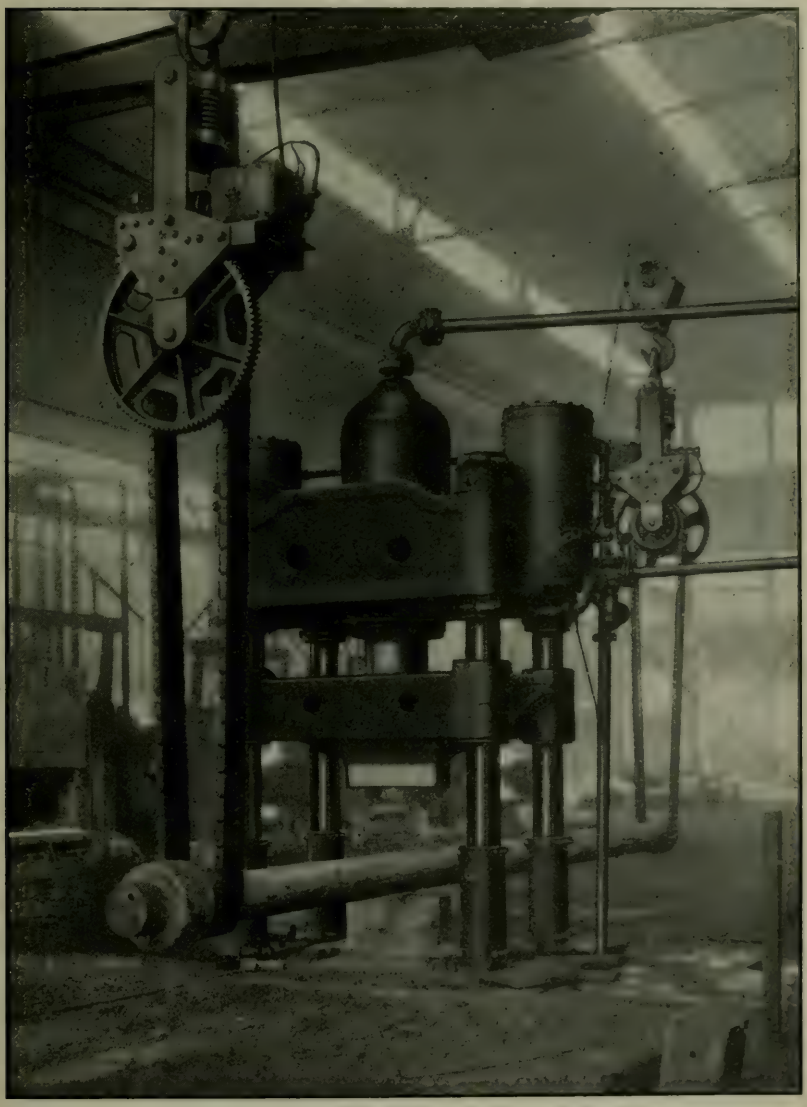


Fig. 5.—A 1000-ton Press Forging a Shaft

temperature, it is removed from the furnace by an electric crane equipped with a motor-driven endless chain belt and placed under the press (Fig. 5, 1,000 tons capacity) for the breaking down operation, which usually begins in the center. The forging operation is directed by the pressman who stands in a prominent position where his signals can be readily seen by the press operator and crane men who must work together. The ingot is worked down in the center first so that subsequent reheatings,

Fig. 6.—Heating Steel for Forging Under the Press.

will be toward the ends of the ingot making it easier to handle after the shaft has been worked out to a considerable length. This working proceeds toward the bottom end, the top end being left until the last as the greatest portion of the discard will come from this end. During the forging operation scale is constantly blown off of the forging and the dies kept clean so that none of this scale is pressed into the forging.

After the bottom end of the ingot has been forged to size, the opposite end is heated and that portion near the center forged out to complete the shaft, the top end being merely roughed down to facilitate handling, as a great portion of this will be discard. In the heating (Fig. 6) of the steel for forging under the press, six furnaces are required to insure operation on a productive basis.

The temperature at which the forging has been finished has

just as important a bearing on the final structure of the steel as the maximum temperature to which it has been heated and it is always the aim of the forgeman to finish the forging as near the upper critical range as possible. The success of the final heat treating depends largely upon the structure of the steel after the forging operation.

On completing the forging it is laid down on a cinder bed where a natural uniform cooling takes place. Sufficient discard to insure sound steel is then made and the forging inspected for dimensions and surface defects, which are properly chipped out before any further work is done on it.

Annealing

The annealing of large shafts calls for properly designed furnaces capable of maintaining a uniform temperature along the entire length, with necessary equipment for handling. The annealing furnaces shown in Fig. 8, are 40 feet long and 54 inches wide, equipped with 11 oil burners, staggered to permit uniform heating throughout. They are also completely equipped with pyrometric control, there being nine thermocouples on each furnace which are connected to a wall indicator for the heater's observation. In addition temperatures are recorded on a recording instrument for future reference, and check.

However, even a pyrometer has its limitations and while it gives an indication of a uniformly heated furnace it does not guarantee that the material in the furnace is heated uniformly throughout, especially if this material be of large cross-section. Here, again, as in the heating for forging, the human element enters into consideration as it is not so much the equipment itself as it is the handling of it, that determines the success of the operation. As an additional check, periodic observations are made through small peep holes in the door of the furnace. The accuracy of these observations depend upon the skill and experience of the operator. The hours for heating are computed on the basis of one hour of heating for each inch of cross-section, care being observed to reduce the saturation above the critical temperature to the shortest time possible and thoroughly heat the steel, as prolonged heating above the critical range will undoubtedly coarsen the grain size.

Quenching and Tempering

Should a forging be ordered to a quenching and tempering specification the routing may be somewhat different. Quite a number of specifications require all forgings above 7 inches in diameter to be hollow bored, and where such is the case the boring operation always precedes the heat treatment. Hollow

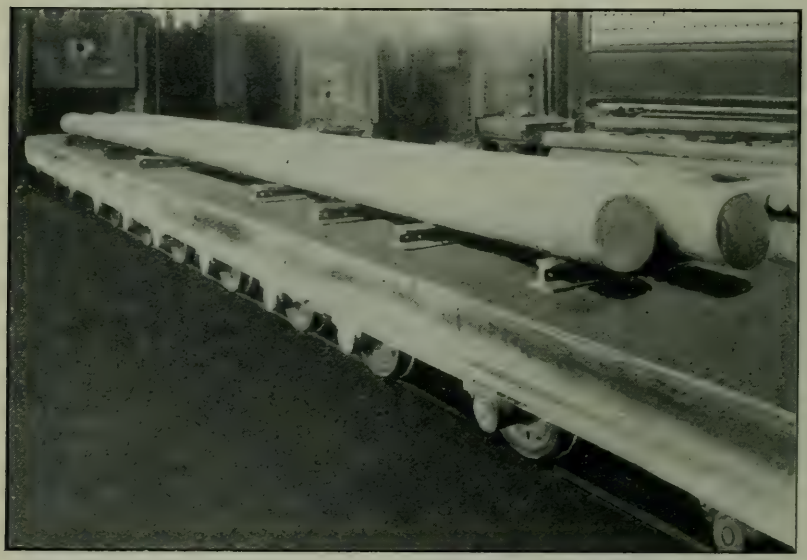


Fig. 8.—Annealing Furnace 40 Feet Long and 54 Inches Wide, Equipped with 11 Oil Burners.

boring (Fig. 9) takes practically nothing away from the strength of the forging, but reduces weight and permits of more uniform cooling in the quenching bath, thereby reducing warpage and increasing the homogeneity of the structure of the steel. At the same time it removes material from the center where defective material is most likely to exist and where it is least subject to the beneficial effects of heat treatment. Examination of the bore has many times lead to the discovery of a defect which would have otherwise remained undetected.

When a forging is ready for the heat treating operation it is placed in a cast steel holder and loaded into a vertical furnace as shown in Fig. 10. The furnace shown is 40 feet deep

and 6 feet in diameter, fired with 18 bull type burners so arranged that the flames swirl around the forging without impinging directly upon it. These burners are accessible from an iron stairway extending to the bottom of the furnace.

Heating for a quench is probably the most important operation in the treating of steel and especially so in respect to large forgings. The same dangers that attend the quenching of a

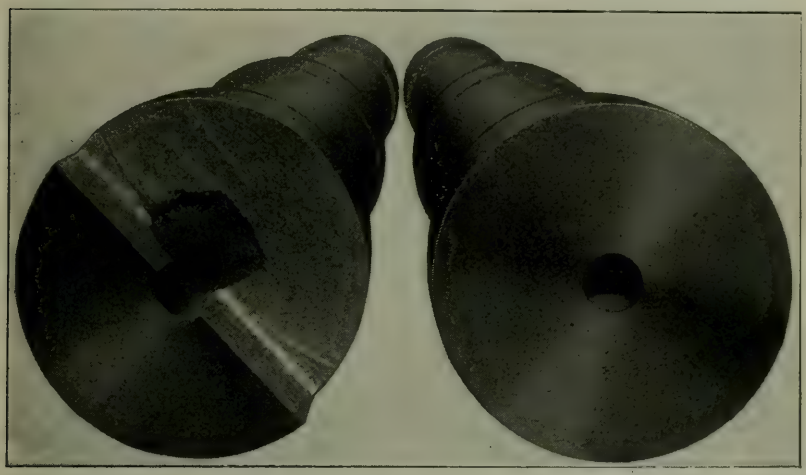


Fig. 9.—Hollow Boring for the Purpose of Removing Defective Centers of Forgings. The Forging on the Left Shows a Defect.

nonuniformly heated tool are in evidence, only highly magnified. We are told that a fairly large section, during the quenching operation, is subjected to tension around the outside, compression midway and tension around the central portion, and unless the steel be sound and uniformly heated, rupture is likely to result.

After the forging has been given the prescribed treatment it is removed from the furnace by a high-speed crane and lowered into the quenching tank immediately adjoining. A soluble oil is used as a quenching medium, it having been found to give the best results after many experiments. With this oil a fairly high elastic limit is possible without the attendant danger of water quenching. The ordinary quenching oils generally used in the heat treatment of smaller material failed to give the desired results due to its lower heat conductivity. Forgings are never per-

Fig. 10.—Vertical Heat Treating Furnace, Oil-Fired Into Which Forgings are Loaded As Shown.

mitted to become cold in the quenching bath, but are removed at between 300 and 400 degrees Fahr.

To keep a bath at a uniform temperature while several tons of red hot steel are immersed in it is a problem of considerable magnitude. To properly care for this a reservoir capable of holding 150,000 gallons of water was built and a system of pipes arranged so that the oil when pumped from the quenching tank circulates through the pipes and then 200 feet away to a reserve tank whence it falls by gravity into the quenching tank again. After quenching forgings are immediately drawn at a temperature necessary to meet physical properties specified, which will at the same time remove all quenching strains.

Tests

Tests are now taken from the end of the forging by means of a hollow drill, midway between the center and the outside and in the direction in which the forging is drawn out. In plain carbon steel of .40-.50 per cent carbon the 'quenched and tempered' specifications will usually require a standard 2″ test specimen to have a tensile strength of not less than 85,000 pounds per square inch; elastic limit 50,000 pounds per square inch minimum; elongation in 2 inches of 22 per cent and a reduction of area between 40 to 45 per cent. In addition, a section ½″ square must bend cold around a 1″ mandrel to 180° without signs of failure. Annealed forgings are usually required to meet 80,000 pounds per square inch tensile strength and 40,000 pounds per square inch elastic limit, 20 per cent elongation in 2 inches and 32 per cent reduction in area. All valves minimum.

After testing for physical properties, all heat treated forgings are given a proof test which consists of dropping a ton weight on the forging, which is rigidly supported on both ends, from a height governed by its diameter, when it is turned ninety degrees and struck again. This will generally weed out any unsound forging.

Microscopic examination is rapidly gaining favor with users of heavy forgings and where this clause is included in the specification, government standards prevail.

DETERIORATION OF STEEL AND WROUGHT IRON TUBES IN HOT GASEOUS AMMONIA*

By J. S. Vanick

Abstract

This paper describes the failure in service of wrought iron and steel tubes employed in an apparatus used for the decomposition of ammonia. The prolonged exposure of the metal to a current of hot gaseous, ammonia produces a localized disintegration, the position of which is determined by the temperature and ammonia concentration.

The progress of the deterioration, with temperature, is similar for both types of material. Details of the macroscopic and microscopic features of the deterioration of the metal, are mentioned in view of their importance in connection with the study of "nitrogenized" steels.

The relations between temperature and the joint reactions representing the decomposition of ammonia and the nitrogenization of iron are briefly sketched to illustrate the general character of the deterioration of steel in heated ammonia.

I. Introduction

MOST investigations concerned with the influence of ammonia on iron or steel have dealt with the effect produced upon the properties through the nitrogenization of the metal by means of short exposures to ammonia, at high temperatures. Usually an exposure of a few hours, or at most 24 hours, in a current of ammonia at a temperature of about 650 degrees Cent., is sufficient to produce the desired degree of nitrogenization. Within this period of time an appreciable change in the mechanical properties occurs which is sufficient to destroy the usefulness of the metal for many structural purposes. The changes in mechanical properties are usually accompanied by differences in composition

*Published by permission of the Director, Fixed Nitrogen Research laboratory, Department of Agriculture, Washington, D. C.

A paper presented before the Detroit Convention of the Society, October 1922 having been revised up to date. The author J. S. Vanick, is research operator in metallurgy at the Fixed Nitrogen Research laboratory, Washington, D. C.

or structure which are readily disclosed by appropriate methods of test.

Where properties such as strength, ductility and hardness are unimportant, steel may be exposed to hot ammonia for relatively long periods of time before destruction by disintegration occurs. At the Fixed Nitrogen Research laboratory, ordinary steel and wrought iron tubes of the following typical analysis, have been used for periods varying from six to nine months before failure by deterioration or "burning through" occurred. A number of tubes, some of which had failed in

	Carbon per cent	Manganese per cent	Phosphorus per cent	Sulphur per cent	Silicon per cent
Steel	0.11	0.38	0.068	0.035	0.008
Wrought iron	0.08	0.37	0.117	0.067	0.006

service, have been carefully examined. The deterioration is quite similar in each case. In view of this, the substance for this paper was abstracted from several reports describing the failures in service of tubes used in the ammonia decomposer, or cracker. The decomposer is an auxiliary unit which is used to "crack" ammonia into its constituent gases, nitrogen and hydrogen.

It consists* (as shown in Fig. 9) of two to four concentric tubes of standard dimensions, fitted one within another with a space of one inch or more between walls. A heating coil is wound about or suspended within an inner tube, to provide the heat necessary for the ammonia decomposition. The intertube spaces with the exception of the one occupied by the heating coil, are packed with steel wool to distribute the heat and facilitate the ammonia decomposition. A thick packing of heat insulating material encases the entire apparatus.

Ammonia gas at a pressure slightly above atmospheric (2 m.m. Hg), is conducted through the intertube spaces and "cracked" into nitrogen and hydrogen. Upon entering, the ammonia gradually absorbs heat; a superheated condition with respect to the reaction NH_3 going over to N_2+H_2 is developed and the decomposition of the gas rapidly takes place. The ammonia content at the exhaust end, is well under 0.5 per cent.

The actual decomposition of ammonia begins with the

*See Larson, Newton, Hawkins, Tour, *Chemical and Metallurgical Engineering*, March 15 and 29, 1922, for additional description.

entrance of the gas into the decomposer. The rate of decomposition at temperatures below 300 degrees Cent. (572 degrees Fahr.) is very slow but in the temperature range from 450 to 650 degrees Cent. (842 to 1202 degrees Fahr.) the reaction rate is appreciably accelerated. This rapid rate is reached in the second tube of the type of "cracker" shown in Fig. 9, and the portion of the tube within which it occurs is referred to as the "cracking zone." Failure by "burning through" occurs in a narrow band or collar near the high temperature portion of this zone.

Temperatures along the outer wall of the "crackers" were measured because of the inaccessability to the interior of the earlier types. In each case, a curve similar to that reproduced in Fig. 9, was obtained. Obviously a slightly higher temperature prevailed in the interior. The position, with reference to temperature of the specimens which were cut from the second tube, are indicated in the diagram. The position of maximum deterioration and failure, corresponded to the position of specimen 3, of the diagram.

II. Service Failures of Wrought Iron and Steel Tubes

It is impossible from the data available from service tests, in which conditions are not strictly comparable, to draw specific conclusions as to the actual value of wrought iron versus steel tubes. Fundamentally, the deterioration from the standpoint of chemical attack, is similar. Physical effects produced during the disintegration, differ characteristically for each type of material. The coarse features of the disintegration are sufficiently accentuated in the wrought iron tube, to distinguish it from the steel, in a preliminary inspection.

An inspection of the tubes after their removal from service, invariably revealed a progressive deterioration from the cooler toward the hotter portions. Blistering, surface-cracking, and fissuring increased with the temperature. The size, number and depth of blisters, was decidedly greater, in the wrought iron tube. Fig. 1, shows a series of specimens representing consecutive sections of an exposed wrought iron tube. The temperature range within which the blisters occur, extends from 400 degrees Cent. (752 degrees Fahr.) upward. The appearance of the surface immediately suggests blister steel.

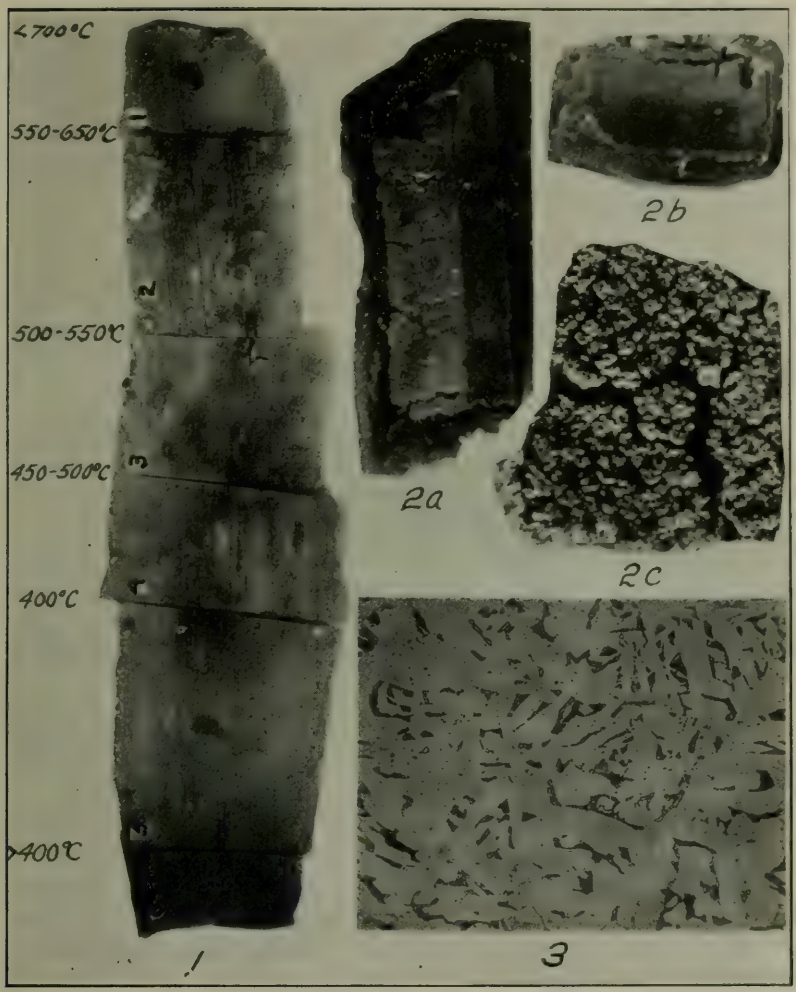


Fig. 1—Sections from Corroded Surface of Wrought Iron Tube. × 1/3. Figs. 2—a, b and c—Severely Corroded "Collar" in Zone III. ×1 2/3. Fig. 2a—Cross Section of Tube in Zone III; Fig. 2b—Cross Section of Tube at Junction of Zones III and IV; Fig. 2c—Surface of Tube in Zone III. Specimens 2a and 2b are Encased in a Plating of Copper. Fig. 3—Microstructure—Unaffected in Low Temperature, High Ammonia, Zone. ×100. Figs. 2 to 8 Represent a Single Steel Tube.

The occurrence of the blisters, is attributed to the action of a reducing gas (in this case, hydrogen), upon the enveloped oxide, silicate or sulphide particles. That a prolonged exposure to the hot gas is necessary, is demonstrated in the failure

to develop blisters in wrought iron specimens heated for 7 days, at 650 degrees Cent. (1202 degrees Fahr.), in a current of ammonia.

The pressures exerted by the expansion of the entrapped gases formed by the decomposition of the inclusions, were sufficient to break through the surface crust or widen internal cavities. Cross sections of the wrought iron tube, revealed deep seated cavities or laminations which tended to separate the wall into sheets along parting surfaces concentric with the curvature of the tube. The laminations apparently formed along the broad, continuous sheets into which the inclusions in the tube had been worked. The infiltration of the gas along the contact between the inclusion and the surrounding metal, followed by the formation and expansion of the products of the gas—versus inclusions reaction had developed the cavities and produced the exfoliated condition in the wall. Microscopic examinations of specimens from the exposed wrought iron tube, showed a distinct decrease in the number of slag strings and in parts a complete disappearance of them. Minute particles, embedded within the grains remained unaffected. No trace of former inclusions could be found in the blister cavities.

In the steel tubes, a thin sprinkling of blisters appeared which lacked the size and depth of those developed in wrought iron. The deterioration of the steel tubes, free of the coarser defects progressed in a more uniform and thorough manner.

The above description sums up the principal differences between the deterioration of the steel and wrought iron tubes. The preponderance of inclusions in the latter and their relation to the sustaining structural fabric, renders the wrought iron susceptable to a more rapid destruction.

III. Macroscopic Features of the Deterioration

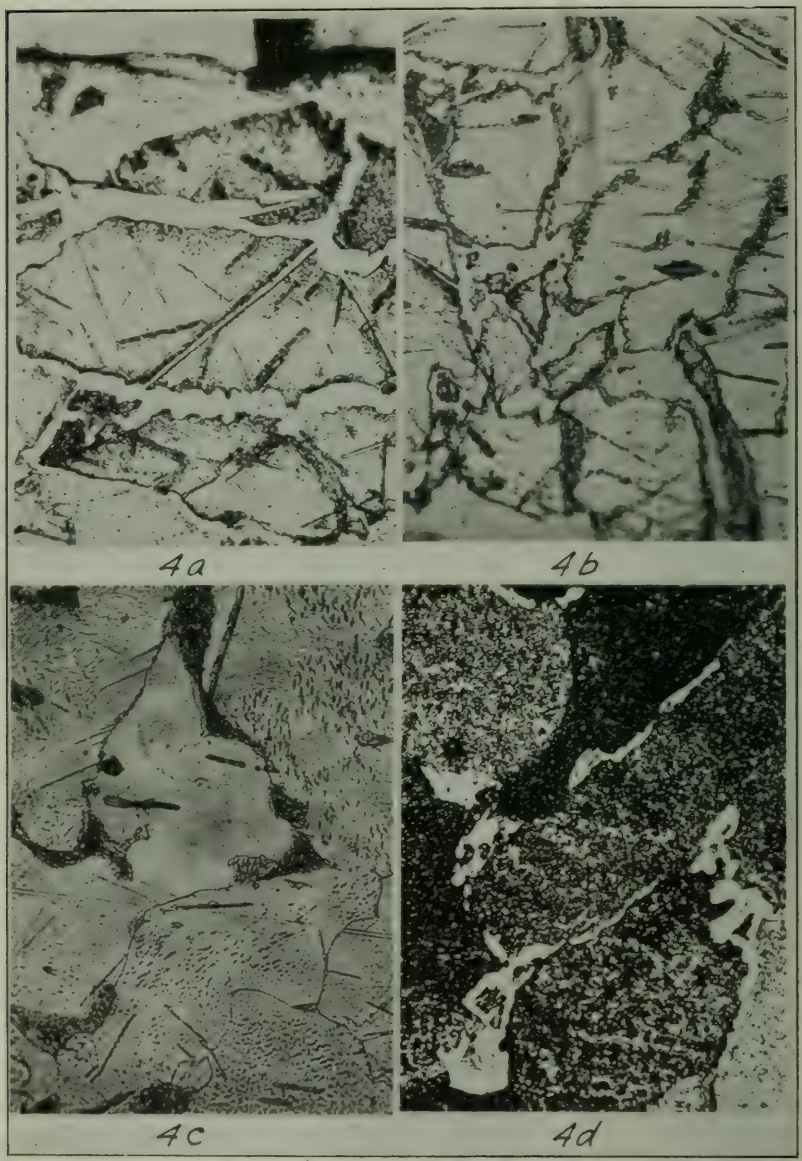
For a more detailed inspection, specimens were cut from positions along the tubes, selected to represent the different temperature ranges. The positions of the specimens within the various zones, are marked in Fig. 9. Each zone presents a change in the condition of the tube which is related to the temperature and ammonia concentration to which the surface

had been subjected. The specimens, with respect to this relation were estimated to lie:

Zone	Temperature Degrees Cent.	Ammonia Concentration
I	below 400	Concentrated—ammonia, zone.
II	400-500	Ammonia concentration, over 80 per cent.
III	500-700	"Cracking" zone, ammonia concentration from 80 to 5 per cent.
IV	700-750	Ammonia concentration 5 to 0.5 per cent.
V	750-680	Ammonia concentration less than 0.5 per cent.

The true relation between each zone and the ammonia concentration of the gas with which it was in contact, has not been specifically determined. It is quite generally assumed that most of the ammonia is decomposed in the severely corroded zone. The decomposition would occur in the position of zone III. Proof of this in the form of actual determinations of the ammonia concentration is lacking, but other evidence which will be mentioned later, tends to support the assumption made.

At the lower temperatures, corresponding to zone I, the tubes appeared to be unaffected by the action of ammonia. Above 450 degrees Cent. (842 degrees Fahr.), in zone II, the surface was covered with a slaty coating which, as subsequent analysis indicated, was the iron nitride. The coating was very brittle and flaked readily, when struck. The coated surface showed no surface cracks. In passing to the higher temperature portion of this zone, the coating gradually disappeared. Surface cracks appeared and prevailed over the remainder of the wall; the crack meshes becoming smaller with the increasing temperature. The cracking was accompanied by a surface roughening which reached a maximum in zone III, and gradually disappeared in zone IV. The appearance of the surface in zone III is pictured in Fig. 2. Fig. 2c shows the alligator cracks and deep fissures which traverse this portion of the tube. The rounded or nodal clusters in the surface, suggest a partial fusion and flow of the surface projections under the action of the heat and the decomposing ammonia. The localization of the attack on the metal is revealed in a comparison of Figs. 2a and 2b, which represent transverse sections



Figs. 4—a, b, c and d—Structures Approaching the "Cracking" Zone. Same Tube as Represented in Figs. 2 and 3. Fig. 4a—Massive Nitride Along Surface, Intergranular Channels and Intercleavage Filling. ×500. Fig. 4b—Same as Fig. 4a, further from Surface. ×500. Fig. 4c—Structure in the Interior Showing Nitride Plates and Patches. ×500. Fig. 4d—Massive Nitride after 30-minute Etching in Sodium Picrate. Ferrite Grains Severely Pitted by the Etching. ×500.

cut within 3 to 4 inches of one another from the severely corroded zone. The fissured, porous, layer which prevails in this portion of zone III, terminates abruptly in the compact appearing backing of the wall. The distinct difference in the width of the fissures and the depth of penetration of the porous layers of specimens 2a and 2b, illustrates the sharply defined localization of the attack. In zone V, the surface roughening does not appear, and the surface, except for microscopic cracks, appears to be unaffected.

IV. Microscopic Features of the Deterioration

A microscopic examination of specimens representing the different zones, to some extent reveals the character of the deterioration. To simplify the description, a single steel tube has been used for the following illustrations.

The results of the microscopic examination may be summarized in a paragraph. Microstructures of the tube sections showed that ammonia is feebly active below 400 degrees Cent. (752 degrees Fahr.). Above 400 degrees Cent. destruction begins and increases with a rise in temperature, reaching a maximum in the 550 to 700 degrees Cent. (1022 to 1292 degrees Fahr.) range. Above this temperature and in the temperature drop that follows, (Fig. 9), the distinct change in the degree of destruction and the character of the disintegration respectively marks a decrease in the intensity of the reaction ammonia going over to nitrogen plus hydrogen and a change in the reaction from decomposition to equilibrium or possibly, to synthesis in the cooler exhaust.

The structure prevailing in the lower temperature, high ammonia zone, is illustrated in Fig. 3. Compounds of nitrogen are not detectable. With the exception of a slight roughening along the exposed edge, the structure is unaltered.

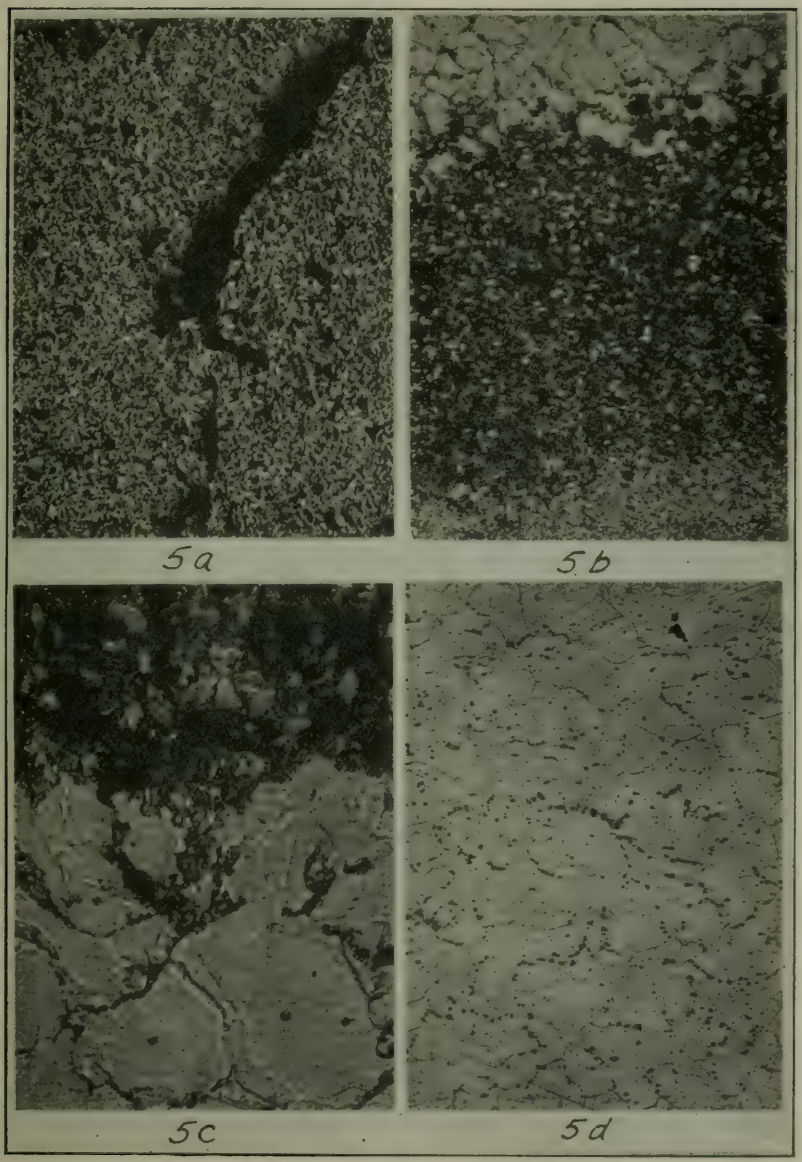
Figs. 4, a, b, c, and d, illustrate the condition of the structure in zone II. As previously mentioned, the surface was covered with a slaty film, which analysis indicated was the nitride of iron Fe_2N. Shavings planed from the coated surface though contaminated heavily by the underlying metal, yielded over 4.25 per cent nitrogen* upon analysis. Figs. 5, a and b, show the junction with the underlying ferrite grains,

*Credit is due L. Smith, associate chemist, for this work.

of the highly reflecting "white layer" of iron nitride. The nitride in this massive form is not limited to the surface but a penetration along the grain boundaries which envelopes the sub-surface grains is evident. The intergranular filling decreases in thickness as the interior of the wall is approached until the massive form is replaced by the plate and patch type of compounds, shown in Fig. 5c. The last traces of carbon appear in this zone. In zones III, IV and V which are heated above 500 degrees Cent. (932 degrees-Fahr.), the metal is completly decarburized. Fig. 4d illustrates the resistance of the nitride to prolonged etching in hot sodium picrate which may be taken to show the absence of carbon and the impossibility of confusing the iron nitride in this massive form, with the iron carbide that it resembles.

It is well to call attention to the thick intercleavage slabs of nitride which traverse the ferrite grains of Figs. 4, a and b, and their resemblance to the nitride plate or needle. The composition of the intercleavage filling is identical with that of the intergranular filling and surface film, as indicated by its structural continuity. The grain boundary contact and intercleavage course which the intruding nitride adopts, is similar to that taken by the thin plates which occupy the interior of this specimen or appear in less severely nitrogenized steels. The needle or plate form of nitride which appears in steels treated in ammonia above 450 degrees Cent. (842 degrees Fahr.) always assumes an intercleavage position and frequently is connected to a thin intergranular film. Finally the occurrence of the plates at or above 450 degrees Cent. which is the temperature at which Fe_2N forms associates their appearance with the formation of this compound. These facts strongly indicate that the plates or needles which are commonly present in nitrogenized steels, are thin intercleavage films of the nitride, Fe_2N.

Of equal interest, are the "white bordered" dark etching patches which appear in the interior of the wall in this zone. The bright border of the dark patches has been described as characteristic of nitrogen bearing steels. The source of this effect is yet a matter of speculation inasmuch as it may appear (as in Fig. 4c) in pearlitic or carbon bearing areas, and again in carbon free areas. In the former case, observations sug-



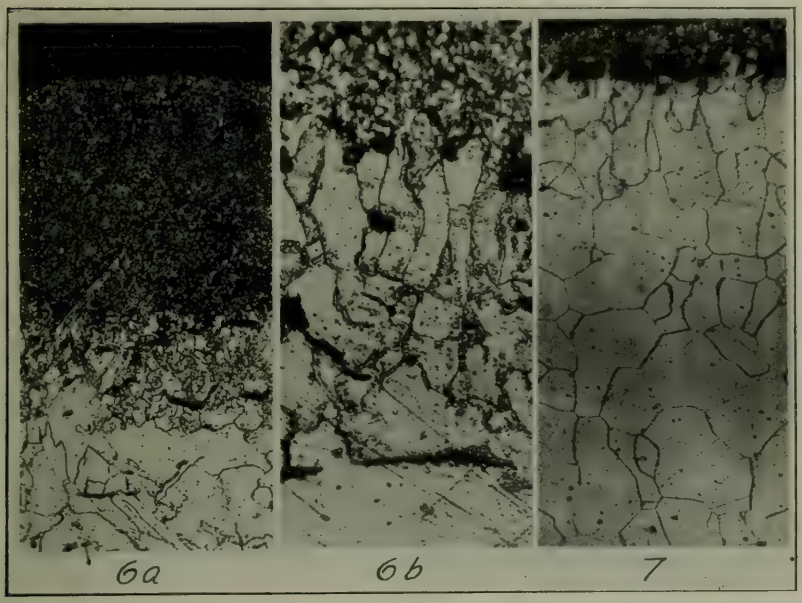
Figs. 5—a, b, c and d—Structures Prevailing in the Corroded Collar of Zone III. Same Tube as Represented in Figs. 2, 3 and 4. Fig. 5a—Structure in Spongy Layer. ×500. Fig. 5b—Darkened Band at the Junction of the Spongy Layer and Pitted Interior. ×100. Fig. 5c—Infiltration of Darkened Band Showing Grain Envelopment. Contour-like Markings Illustrate Grain Uplift. ×500. Fig. 5d.—Intergranular Pits in "Compact" Backing. ×100.

gest, as an explanation of the relation between the brightened edge and pearlitic center, a gradual replacement of the cementite (Fe_3C) by the nitride Fe_2N. The inability to detect cyanides in a sample possessing this type of structure, and the loss in carbon which is detected, indicates that a volatile hydrocarbon, is produced. A reaction summarizing the result, might be advanced, in which the action of dry ammonia upon the iron carbide in this temperature range, produces, as end products, the nitride of iron and a volatile hydrocarbon. Future research will doubtless determine the character of this reaction. In the absence of carbon, the brightened border, probably represents an iron nitride shell which might be expected to form on the exterior of the darkened, iron nitrogen solid solution, during slow cooling. The recession of the solid solution, from the ferrite matrix, during cooling, with an attendant increase in the nitrogen content of the littoral layers of the receding solution, would accumulate sufficient nitrogen along the edges to form the iron-nitride shell.

The severely corroded portion, corresponding to zone III revealed a disintegration of the compact crystalline structure into a coky or spongy mass. In the region of the failure, the disintegration had progressed completely through the wall. Fig. 5a, shows the porous texture of the spongy skeleton that remains. Figs. 5b, c and d show the structure within a specimen corresponding in degree of deterioration, to the one pictured in Fig. 3a. When fractured, the dark, spongy layer seemed to be firmly attached to the compact outer skin. The junction is shown in Fig. 5b. Within the spongy zone, and penetrating into the fissured outer skin, a darkened band appears which marks the position of the iron nitrogen solution in the structures* The solution makes its advance along the intergranular channels, gradually enveloping the grains encountered in its progress, as shown in Fig. 5b. Since this structure is confined to this zone, it seems to be defined by the ammonia concentration and temperature conditions, prevailing. A peculiar change in the surface band of the ferrite is noticeable in the region bordering the farthest ad-

*Knight and Northrup, *Chemical and Metallurgical Engineering*, volume 23, No. 23, December 8, 1920, page 1107, have reported the appearance of a pearlitic layer in carburized steel heated in ammonia at 650 degrees Cent. Similar tests at this laboratory have developed the darkened band in pure iron. The area often lacks the structural form typical of eutectics and fails in other respects to satisfy eutectic requirements.

vance of the dark constituent. An uplift of the structure in the direction of the less affected interior, produces a secondary boundary which like a contour marking, follows the outline of the dark constituent. Fig. 5c records an example of this.



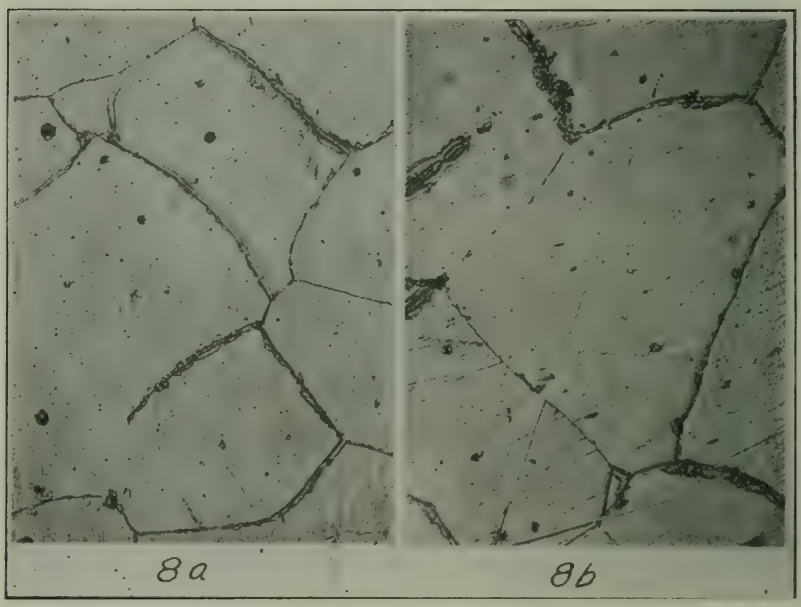
Figs. 6a and 6b—Structure in a Section Adjoining the Corroded Collar of Zone III. Fig. 6a—Spongy Edge. ×100. Fig. 6b—Grain Fragmentation at Junction of Spongy Edge with Fissured Interior. ×500. Fig. 7—Surface Attack in High Temperature, Low Ammonia Zone. ×100. Same Tube as Represented in Figs. 2 to 6.

The effect suggests an infiltration of gas into the compact grain structure, producing an expansion of the crystal lattice with an attendant swelling or decrease in density of the affected portion.

In the outer edge of the wall, the decarburized and perforated structure, shown in Fig. 5d, occurs. The structure is that of ferrite, interwoven with fissures and intergranular pits.

The occurrence of the dark band at the junction of the fissured interior with the spongy exterior, associates its presence with the severe disintegration. Apparently the disintegration consists of a decarburization and fissuring, as indicated in the interior and outer edge; followed by nitrification

marked by the darkened band; followed in turn by decomposition of the nitride so formed, which leaves the spongy, iron residue in its wake. The disintegration in a section adjoining the corroded collar of zone III shows a marked decrease in the severity of the ammonia attack. Figs. 6a and b, illustrate the



Figs. 8a and 8b—Structures in the Exhaust Portion of the Tube Show the Effect of Nitrogen and Hydrogen at High Temperatures. Same Tube as Shown in Figs. 2 to 7. Fig. 8a—Etching Fluid Exudations along Grain Boundaries Indicate Intergranular Fissuring. ×500. Fig. 8b—Another Spot, Similar to ("a") Showing Diffusion Rings Around Slag Inclusions. ×500.

structure along the exposed surface in this section. The advance of the darkened band seems to be preceded by the breaking up of the encountered grains. Mechanically, the destruction appears to progress in 3 stages.

1. Intergranular fissuring.
II. Grain dislodgment and partial fragmentation.
III. Thorough fragmentation of the dislodged grains.

The first stage consisting of an intergranular fissuring is similar to that described for Fig. 5b. The fissures penetrate completely through the wall. Fig. 6a, shows the spongy edge, which is darkened by the iron nitrogen solid solution. In

this case the contact of the fissured interior with the spongy edge, is marked by a band of broken grains. The contact is better shown in Fig. 6b. The change in the character of the disintegration is no doubt due to the lower ammonia concentration and higher temperature to which this section is exposed. In the high temperature, low ammonia regions, a slight surface disintegration and decarburization, is evident. Fig. 6a, reveals the edge of a specimen in zone IV which shows the depth of the disintegration as marked by the thin black band. A complete decarburization of the underlying metal is apparent.

The surface disintegration of zone IV does not appear in zone V at the exhaust end of the tube. The heat cracks or fissures appear to be limited to the surface of the tube. The brittleness of the metal prompted a further inspection and a close examination showed that the structure was interwoven with a net work of very fine fissures. Etched specimens, if allowed to stand, would upon examination, show thin intergranular films around the ferrite grains. These films proved to be dried exudations of the etching fluid. By observing a freshly etched surface for a few minutes a film of the etching fluid would appear along the grain contacts and gradually spread over the neighboring surface. This effect repeated at will, definitely proved the presence of intergranular fissures. Figs. 8a, and 8b, illustrate fissure exudations.

Attention might be called to the diffusion rings or halos which surround particles of embedded slag as shown in Fig. 8b. These rings apparently represent the progress of diffusion into the matrix of the decomposition products of the reaction between the slag and the gases. The micrograph shows that particles that are thoroughly embedded within the grains, are very slowly attacked.

V. Discussion of General Relations Between Temperature and the Reversible Gas-Metal Reactions

An attempt to explain the condition of the structure and its relation to the deterioration, requires a general reference to

the changes with temperature of the reversible ammonia—iron reactions:

1. $4\ Fe+2NH_3=2\ Fe_2N+3H_2$.
2. $Fe_x+2(NH_3)_y=Fe_xN_y+3_yH_2+N_2$ and the ammonia equilibrium reaction;
3. $2NH_3=N_2+3H_2$.

It is quite generally known that the nitride of iron, Fe_2N,

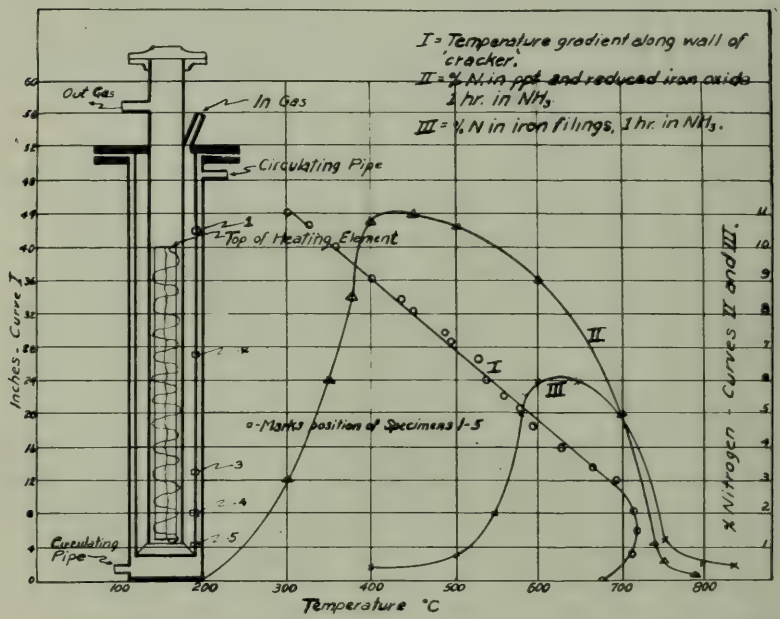


Fig. 9—Sketch of an Ammonia "Cracker" of the Two-tube Type. Third or Outer Tube Serves as a Jacket Containing Still or Slowly Circulating, Non-oxidizing Gas, such as Nitrogen, Hydrogen or a Mixture of the two. Curves II and III (after Tschischewski) Plotted against Temperature Gradient Curve I.

forms at 450 degrees Cent. (842 degrees Fahr.) when iron is exposed to a current of ammonia. Early reference to this, dates back to the work of Despretz*. The nitride is unstable above 450 degrees Cent. and its decomposition proceeds with higher temperatures. Tschischewski**, reporting the nitrogenization of iron by ammonia, obtained curves II and III of Fig. 9, for the variation in nitrogen content with temperature. The curves show a similarity in form. The lowered maximum and the displacement in the direction of higher temperatures of

Ann. Chim. phys. 1829 Vol. 42, p. 122.
***Journal Iron and Steel Inst.* 1915, vol. XCII, No. 2, p. 47.

curve III might be expected in view of the limited time of exposure and the probable concentration gradients from surface to center, of the coarser particles of the material used. The surface of the exposed decomposer tubes should, however, conform more closely to the form of curve II, because of the extended time of exposure.

As in the conversion of nitrogen and hydrogen, into ammonia, the decomposition of ammonia involves a time factor which is a measure of the reaction velocity. The rate of ammonia decomposition, becomes very rapid in the temperature range of 450 to 650 degrees Cent. (842 to 1202 degrees Fahr.). A curve representing the rate of decomposition with changes in temperature would undoubtedly be of the 'U' shaped type with its apex at 500 to 550 degrees Cent. (932 to 1022 degrees Fahr.). The lower temperature portion of the rapid decomposition range (400 degrees Cent.) coincides roughly with the temperature at which the nitride of iron, is formed. The latter decomposes slowly in comparison to the rate of decomposition of the ammonia. For this reason, the region of maximum deterioration lies in the zone in which reaction 3 predominates.

In following the progress of the reactions with changes in temperature; it has been shown that the temperature in zone I had been too low for the formation of nitride. The quantity of ammonia decomposed, had likewise been insignificant. In zone II, evidence of the progress of the reactions 1 and 2, is visible in the formation of the surface coating, nitride plates and darkened patches. The degree to which reaction 3 had progressed is speculative, since but little decarburization is noticeable. Reaction I predominates, as indicated above; its progress probably being impeded by the thick surface coating of nitride which is formed. In zone III reaction 3 has reached its maximum velocity while reaction 1, is partly replaced by reaction 2. The solution of nitrogen and iron which is formed is not protected by a surface layer until an appreciable decomposition has occurred. Then the spongy skull that forms might retard the destruction slightly, by acting as a porous filter, and cracking the infiltering ammonia, but this protection would be negligible. Evidence of the presence of an appreciable amount of hydrogen is shown in the freedom

from carbon of this portion and of the balance of the tube. Beyond the cracking zone, the thin disintegrated layer along the surface in zone IV indicates the action of a small percentage of residual ammonia. The absence of nitrogen compounds shows that reaction 3 had begun to approach equilibrium. This same feature but lacking the surface disintegration in zone I indicates that equilibrium with respect to reaction 3, had been attained. In fact the drop in the temperature over the exhaust portion of the tube would favor the synthesis of a small amount of the available nitrogen and hydrogen.

VI. Summary

I. The failure in service of wrought iron and steel tubes employed in an apparatus used for the decomposition of ammonia, is described. The prolonged exposure of the metal to a current of hot gaseous, ammonia produces a localized disintegration, the position of which is determined by the temperature and ammonia concentration.

2. The progress of the deterioration, with temperature, is similar for both types of material. Details of the macroscopic and microscopic features of the deterioration of the metal, are mentioned in view of their importance in connection with the study of 'nitrogenized' steels.

3. The relations between temperature and the joint reactions representing the decomposition of ammonia and the nitrogenization of iron are briefly sketched to illustrate the general character of the deterioration of steel in heated ammonia.

NOTES FROM THE BUREAU OF STANDARDS

Thermal Stresses in Steel Car Wheels

SOME of the work of the Bureau of Standards in testing car wheels has been described in previous reports of the bureau. In 1920 a conference of several representative manufacturers and purchasers of steel car wheels was held at the bureau to discuss plans for conducting an investigation of the thermal stresses developed in the plates of such wheels through heating of the rim during long brake applications. As experienced railway men stated that sometimes the tread becomes heated to a dull red, it was agreed that such an investigation would be of general interest and value to the steel wheel industry.

Eight worn 33-inch wheels were furnished by the Pennsylvania railroad and nine new 33-inch wheels were furnished by several different manufacturers. One or more tests were also made on two special designs of wheels, the first with a thin plate, and the second with a straight plate. The wheels tested were representative of the five methods of manufacture in common use and were mounted in such a way that the axle was kept cool by running water while the tread could be heated by means of electrical resistor close to but electrically insulated from the tread. Thermocouples were inserted at approximately 2-inch intervals to determine the temperature distribution, while the radial stresses developed in the plate on both the face and back were indicated by means of strain-gage measurements. The tensile properties and coefficient of expansion of the material from which the wheel was made were determined in auxiliary tests. The stresses were only calculated radially on the face and back of the plate since preliminary measurements indicated that the tangential stresses were of a compressive nature and of small magnitude.

Ordinarily the tread of the wheel was heated to a temperature of about 380 degrees Cent., but in the case of two new rolled wheels and one cast wheel, the treads were heated to the highest temperature attainable with the equipment, about 500 degrees Cent. Considerably more time was required to reach this temperature than to reach the temperature of 380 degrees Cent., but the stresses were no greater. The geater strain appeared to be offset by the greater expansion resulting from the higher temperature, thus giving a flat stress time curve between 380 to 500 degrees Cent.

The most interesting features revealed in these tests may be summarized as follows: (1) None of the wheels failed; (2) When the rim is heated, the hub moves with respect to the rim inducing stresses in the plate. For the first test on new wheels these are in tension near the hub and in compression near the rim on the face, while on the back of the plate, the stresses for the same locations near the hub and rim are about equal in magnitude

but of opposite sign; (3) For worn wheels, the stresses are of the same character except near the rim on the face where very little stress is found. This difference is due to shifting of the neutral axis on the face brought about by conditions of service; (4) The maximum stresses are on the surface and slightly above the yield point of the material which averages about 50,000 pounds per square inch as determined in tensile tests; (5) A permanent set resulted only in the case of new wheels on the first test. For worn wheels and in succeeding tests on new wheels, no set was apparent, showing that stresses above the yield point were not increased by repeated heating and that through the effects of service the old wheels had been brought to a condition approximating that of the new wheels after the first heating; (6) For all forged wheels, the character and magnitude of the stresses are but little affected by the method of manufacture. Because of the corrugated plate, the stresses developed in the cast wheels were more complicated than those in the forged wheels; (7) The special rolled wheel with the thinner plate ½-inch thick developed stresses similar to those in the wheels of regular design but of somewhat greater magnitude, while the stresses produced in the special straight plate wheel were in pure tension on both the face and back of the wheels.

This work is described in detail in Technologic Paper No. 235 of the Bureau of Standards which will be available at an early date from the superintendent of documents, government printing office, Washington, D. C.

Etching Reagents for Alloy Steels

This investigation which has been in progress at the Bureau for some time has yielded the following results to date: The metallographic etching of alloy steels with the usual acid etching reagents fails to identify the different constituents that may be present in the alloy steel, such as the carbide of iron, chromium, tungsten or vanadium, tungstide of iron, and possibly complex compounds as double carbides. This is a particular importance where two or more of the constituents are present simultaneously in the microstructure as has been found to be the case with high-speed steels and iron-tungsten-carbon alloys.

It was seen early in the investigation that, on the one hand, the use of the usual inorganic acids offered little hope of success because of the general resistance of the above-mentioned constituents to the corrosive action of the acids, while, on the other hand, alkaline solutions of an oxidizing nature offered considerable promise in producing distinctions by means of etching characteristics. A little experimental work was next carried out on various alkaline solutions with and without the use of oxygen gas or oxidizing agents, the results of this work being the develop-

ment of a new etching reagent, namely, a potassium permanganate and sodium hydroxide mixture.

With the object of establishing the identity of the metallographic constituent known or believed to be present in the microstructure by noting its behavior toward the various etching reagents, etching tests were made on various amounts of the alloying element and of carbon. For this work a number of etching reagents of an alkaline nature, among which were several well-known reagents, such as sodium picrate, Yatsevitch's reagent, etc., were used. Heat-tinting was also tried. The method of sequence etching or etching with two or more reagents in succession without any repolishing of the specimen between the etchings was used with success in cases where more than one constituent is present in the microstructure, as in high-speed steels.

The results obtained so far show that it is possible, by proper selection of the etching reagent, to determine in a satisfactory manner the presence or absence of the different constituents in the micro-section and also to distinguish between several of the constituents when two or more are present in the same micro-section, as, for example, cementite and chromium carbide, or cementite and iron tungstide. No method has as yet been found for distinguishing between chromium carbide and tungsten carbide other than from a consideration of the shape of the particles which these constituents have been found to assume should both occur in the same micro-section.

Gases in Metals

Tests conducted at the Bureau of Standards on the completeness of recovery of oxygen from oxides of iron and silicon in the vacuum fusion method for gases and metals have indicated complete reduction and recovery in both cases. Other oxides which may be present in steels are now being tested. Through the cooperation of a manufacturer of malleable cast iron, some tests have recently been made which indicate that the results for oxygen by the Ledebur method on white cast iron are of little value because of the surface oxidation of the sample during its reduction to a finely divided form. The apparent oxygen content of the metal as a fine powder is about 100 times, and as a coarse powder about 50 times the true oxygen content of the material, as given by vacuum fusion analysis on a solid sample.

Heat Treatment and Properties of Magnet Steels

The Metallurgical and Electrical Divisions of the Bureau, in co-operation, are beginning an investigation to determine the effects of various heat treatments upon the characteristic properties of the steels now used commercially or suggested for use in the manufacture of permanent magnets. During the past month

about 10 samples were hardened, and it is hoped that they will soon be ready for the first magnetic tests.

Non-Destructive Testing of Wire Rope

The Bureau of Standards is about to undertake an investigation of the possibilities of using non-destructive methods for testing wire rope with special reference to hoisting rope. Present methods of inspection are unsatisfactory and do not unfailingly tell when it is necessary to remove the rope from service. The object of this investigation is to develop, if possible, some method by which an actual test can be made to determine the condition of the rope with respect to its deterioration in service, without destroying it. An advisory committee is being organized which will be composed of representatives of the principal interests connected with the manufacture, use, and testing of wire rope, and the first meeting of the committee was held at the Bureau on June 16 for the purpose of discussing plans and methods of procedure in the work.

Steel for Brinell Balls

In measuring the hardness of metals by the Brinell method, a hardened steel ball is forced into the specimen by hydraulic pressure, the amount of penetration serving as an indication of the hardness of the sample. Difficulty has been found in measuring the Brinell hardness of steel having a hardness over 500 B. h. n. An attempt has been made by the Bureau for the past 3 or 4 years to obtain a very hard steel which will carry the load of 3000 kg. without fracture, but up to the present without success. Tungsten carbide has been suggested, but it has been impossible to obtain this material in suitable condition in either this country or Germany. Recently a very hard vanadium steel made at the Bureau's laboratories has been tried and shows promise of success. More of it will be made, and if future experiments are successful, an important advance in the art of hardness testing may result.

Scratch of Hardness of Copper

The Bureau of Standards is conducting an investigation of the instrument used for the determination of the scratch hardness of metals, and in connection with this work, considerable attention has been given in respect to the affect of various amounts of cold working on the hardness of copper. The results obtained in cold rolling very pure, electrolytic, unmelted copper and also ordinary commercial copper indicate clearly that the early stages of the deformation of the metal harden it very rapidly. The maximum degree of hardness is soon reached, however, and a reversal occurs, the metal becoming very appreciably softer as the deformation process is continued, so that the metal in

its final condition after cold rolling is completed is softer as measured by the scratch hardness method than in its initial state. These results were confirmed by tests made on the same material by the micro-Brinell method. Annealing cold-rolled sheets at a low temperature (100 degrees Cent.) softens the material appreciably, but the general form of the hardness deformation curve is not affected.

The work will be extended to a few other metals to determine whether this behavior is peculiar to copper or more general in its nature.

THE CRYSTALLIZATION OF IRON AND ITS ALLOYS

Concluded from Page 45

mal critical range, and through that range so as to obtain the cast structure most suitable to our purpose, namely, a net work structure, a Widmanstätten structure or a "mixte" structure. We should bear in mind that dendritic segregation is not removed by the usual heat treatments, and that when the steel ingot is subjected to hot working, between the solidus and the thermal critical range, a banded structure is necessarily produced and directional properties imparted which will be the more pronounced the greater the reduction of the cross section. We should, therefore, abandon the belief that the more we work steel the more we improve its physical properties. If the finished implement is to be subjected to transverse stresses, excessive reduction is very detrimental whenever persistent dendritic segregation exists.

The author desires to record here his appreciation of the work performed in his laboratory during the last two years by E. L. Reed, instructor in metallurgy, and Carnegie research scholar, and by V. D. Krivobok and D. C. Lee, candidates for the degree of Doctor of Science, who have conducted most of the experiments described in this paper and many others which may bear fruit later. Their industry and enthusiasm have been an inspiration.

NOTES FROM THE BUREAU OF MINES

Improving the Efficiency of the Blast Furnace

THROUGH its investigations into (1) the reactions taking place at certain zones in the blast furnace, (2) the effect and elimination of sulphur in coke, and (3) the use of oxygenated or enriched blast, the Department of the Interior, working through the Bureau of Mines, hopes to reach definite conclusions which will be of considerable benefit to the iron and steel industry.

At its Minneapolis experiment station the Bureau of Mines has made several smelting campaigns, these including the regular sampling and determination of gases at fixed planes in the blast furnace, from which certain deductions can be made. Another run is under way during the past month. Trials are also being made with oxygenated blast.

The behavior and elimination of sulphur in coke is being studied at the bureau's Pittsburgh experiment station, this revealing some interesting facts regarding the absorption of sulphur by the iron inside the furnace.

The possibilities of using oxygenated blast are many, and include (1) the elimination of hot stoves; (2) the use of an excess of coke to prevent chilling and freezing; (3) the elimination of sulphur; (4) allowance of the utilization of high-phosphorus ores; (5) improvement in Bessemerizing; and (6) lower costs. A committee of ten metallurgists, chemists, and engineers, including five Bureau of Mines men, is studying this phase, and will shortly issue a preliminary statement thereon.

Shells In Strip Steel

The result of an analysis of data on open-hearth practice resulting in shelly strip steel, made by F. B. Foley, metallurgist of the Department of the Interior, at the Mississippi Valley experiment station of the Bureau of Mines, Rolla, Mo., showed that heats which produce shells are shorter heats, that they take more ore, and less spar and that they give a lighter ladle skull than those that produce metal free from shells. The indication is that shells are the result of running the heat in the open-hearth too hot and bringing down the carbon too fast by oreing. The metal is thus apparently over-oxidized.

Coal-Fired Furnaces

Manufacturers and operators of the larger coal-fired furnaces can not afford to disregard the possible advantages of pulverizing their coal before burning it, states John Blizard, fuel engineer of the Department of the Interior, in Bulletin 217, recently issued by the Bureau of Mines. The bulletin, which

contains information, regarding the preparation, transportation and combustion of powdered coal, is published through the courtesy of the Canadian Department of Mines, for whom the bulletin was originally prepared.

Powdered coal has been successfully applied, and is commonly used in open-hearth furnaces; busheling and puddling furnaces; continuous-heating furnaces for blooms and billets; furnaces for heating, reheating, and forging, annealing furnaces for malleable iron and steel castings and plates; sheet and pair and annealing furnaces and tin pots; galvanizing pots; soaking pits; ore roasting and volatilizing; copper-ore roasting and smelting; the zinc industry; the gold and silver industry; calcining kilns; lime burning; refractory materials; and also in the fertilizer industry. It is used more than any other fuel in the cement industry and has been successfully applied for steam raising. Whenever powdered coal has displaced hand firing the coal consumption has been reduced considerably.

By the term powdered coal is meant coal subdivided so that it may be burned in suspension when mixed with the necessary supply of air and may be conveyed easily by means of a screw conveyer, by compressed air, or suspended in a steam of low-pressure air to the furnace.

Since the coal has to be pulverized, it is usually better to purchase slack coal, which is usually cheaper and costs less to pulverize.

The requisite composition of the coal depends upon many factors. Practically all coals from lignite to anthracite, and even coke breeze have been pulverized and burned. But anthractite and coke breeze require more energy to pulverize them than softer coals, and low-volatile coals are difficult to ignite and must be burned in specially designed furnaces.

One of the principal difficulties in burning powdered coal lies in the disposition of the ash; and for this reason it is desirable also to use a coal which contains little ash and that melting at a comparatively high temperature.

The power used to pulverize and convey similar coals to the burner is approximately proportional to the weight of the coal pulverized, and it is clear that the pulverizing and conveying costs will, therefore, be greater per heat unit delivered the lower the calorific value of the coal.

A powdered-coal plant consists of apparatus which converts raw coal into powder and conveys it to the furnace, into which it is delivered as required and burned in suspension. The systems used to accomplish this may be divided into two classes: (1) The unit system, in which one machine prepares and delivers the coal to the furnace with the necessary air for combustion, and (2) the multiple system, in which the coal is

prepared in one building and transported to another building wherein is situated the furnace in which the coal is to be burned.

The principal advantages over hand and stoker firing lie in the comparative ease of conveying coal to furnaces and in the practically complete combustion of the coal, with little excess air, in close contact with the material to be heated, thus avoiding the convection, radiation, and excess-air losses which accompany hand or stoker-fired furnaces placed outside reverberatory and many other furnaces. For this reason the most successful field of use of pulverized coal installations has been for those purposes where they have replaced externally fired furnaces. For purposes such as steam raising, where the burning coal can give up heat directly by radiation to the boiler heating surface, there is, therefore, less opportunity for reducing the fuel consumption by burning powdered coal instead of burning coal on a grate, since the losses which may be reduced by substituting powdered coal firing for hand firing or stoker firing are those only which are due to incomplete combustion and using excess air. These losses, however, are not inconsiderable.

Certain drawbacks to the use of powdered coal are cited by the author of the bulletin. Before powdered-coal firing can compete successfully with grate firing it is obvious that the gain due to the smaller consumption of powdered coal must offset the cost of preparing, conveying, and burning it.

There is a further disadvantage with powdered coal. In grate firing the ash is left on the grates and in the ash pit. But with powdered coal the ash is blown into the furnace, out through the stack, and with some badly designed furnaces out through openings in the furnaces. It may also form a troublesome slag, and fill up the flues so as to impede the draft.

On the whole, powdered-coal plants can not be said to be clean. There are fairly clean powdered-coal plants; but generally, though not universally, a plant using powdered coal is dirtier than a grate-fired plant.

Powdered coal is better adapted for firing stationary water-tube boilers than other boilers. With these boilers furnaces of sufficient size and of the correct shape may be constructed, and the gases pass through no tubes wherein ash may settle to obstruct the draft and shield the heating surface. It has been found difficult to burn powdered coal in locomotive and cylindrical marine boilers because the combustion space is too small to permit the coal to be burned completely.

Although men have been killed by explosions and fires in powdered-coal plants, the causes of such accidents are known and precautions may be taken that they may not recur.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 86—Can ingotism in steel be removed by subsequent rolling or forging?

QUESTION NO. 87—What is the reason for the distortion of gears made of S. A. E. 3120 steel after carburizing according to recommended heat treating practice of the S. A. E?

ANSWERS OLD QUESTIONS

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel?

QUESTION NO. 71. How do the physical properties compare between a 0.35-0.45 per cent carbon acid open-hearth steel and an alloy steel of either 3.5 per cent nickel or 1.5 per cent nickel and 0.50 per cent chromium neither heat treated?

ANSWER. By J. S. Vanick, research operator, fixed nitrogen research laboratory, department of agriculture, Washington, D. C.

The approximate tensile properties of the annealed steels of the composition mentioned, are as follows:

Composition			Tensile	Yield	Red	Elong.
Carbon per cent	Nickel per cent	Chrome per cent	strength lbs. per sq. in.	point lbs. per sq. in.	area per cent	2 inches per cent
.35	..	..	64,000	48,000	62	29
.45	..	..	71,300	57,500	54	23
.35-.45	3.5	..	73,000	58,000	50	23
.35-.45	1.5	.60	75,000	60,000	45	20

No comparison can be made between "untreated" steels, if a strict interpretation of the term "heat treat" is used. Since manufacturing processes vary, untreated steel would mean steel from any source, in bar, billet, or finished form, which had not received the attention necessary to eliminate differences in condition introduced during the manufacturing process.

No steel should be used without being annealed either by the user or by the manufacturer. Most steels in bar sizes are subjected to a "mill anneal" by the manufacturer. Many products receive treatment equivalent to annealing by being finished at suitable temperatures and cooled under carefully controlled conditions. In any case, a comparison of tensile properties is not justified until a common level, with respect to the condition of the steel, is reached and this level in its most simple form is attained in the annealed product.

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 76. Why are cold drawn carbon and high-speed steel sometimes supplied with a copper coating? Does this coating affect the steel in any way, or is it merely a lubricating agent in the drawing process? Is it necessary or desirable to remove the coating before hardening?

ANSWER—By B. F. Weston, Jones & Laughlin Steel Corporation—S. S. Works, Beaver Falls, Pa.

The cold drawing of steel presents a condition requiring great efficiency in lubrication, as may be imagined, and while many substances are used in drawing ordinary soft grades of steel, the use of some substance entirely preventing the "galling" and scratching of the bar being drawn in the case of harder material.

A heavy grease of the lime or aluminum soap type may be used, a light copper coating is desirable, which would not be likely to injure the steel except for use in some special

cases. The copper acts only as a lubricant, and while it is not necessary to remove the copper coating before hardening, the writer believes it desirable.

QUESTION NO. 82. What analysis steel is most suitable for punching out hot work on upsetter in drop forge shop?

ANSWER. The most suitable steel for piercing-punches and shear-dies used for hot work on upsetting machines is one having the following approximate analysis:

Carbon per cent	Manganese per cent	Chromium per cent	Vanadium per cent	Tungsten per cent
0.50	0.30	2.75	0.40	14.00

Phosphorus and sulphur as low as possible.

Preheat to 1600-1700 degrees Fahr., heat to 2100-2150 degrees Fahr., quench in oil, draw at 1050 degrees Fahr.

Should a steel be required to withstand severe shock in addition to heat, the following approximate analysis may be found more suitable:

Carbon per cent	Manganese per cent	Chromium per cent	Vanadium per cent	Tungsten per cent
0.25	0.30	3.25	0.25	8.00

Phosphorus and sulphur as low as possible.

Preheat to 1600-1700 degrees Fahr., heat to 220-2350 degrees Fahr., quench in oil, draw at 1050 degrees Fahr.

Another analysis suitable for some kinds of hot upsetting work is approximately:

Carbon per cent	Manganese per cent	Chromium per cent	Vanadium per cent	Tungsten per cent
0.50	0.35	1.50	0.20	2.50

Phosphorus and sulphur as low as possible.

Heat to 1750-1800 degrees Fahr., quench in oil, draw at 900-1050 degrees Fahr.

The following chrome steel has also been found satisfactory for some kinds of hot upsetting work:

Carbon per cent	Manganese per cent	Chromium per cent	Vanadium per cent
0.85	0.40	3.50	0.15

Phosphorus and sulphur as low as possible.

QUESTION NO. 83. In annealing high carbon tool steel in an open fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 84. What is the effect on the steel being forged, through the use of high velocity blows during drop forging?

ANSWER—By Henry Hayes, London, England.

Though the statement may not be readily accepted, it has been found by experience that high velocity blows fill the die better and use less material. In a drop hammer, the velocity of the falling weight is determined by the height of the fall. In the steam drop hammer of the direct-acting type, the stroke is shorter, but is compensated for by the steam pressure behind the piston. As the velocity increases with the steam pressure the tup strikes the work with a higher velocity than in the gravity drop stamp. The lift off is also quicker in the steam hammer, therefore the period during which the heated steel is in contact with the dies is reduced—greatly to the advantage of the dies.

The problem of the speed of the blow is one which has not yet received the metallurgical and mechanical consideration that its importance warrants. It is known that there is a great difference between the work performed by a hydraulic press and a steam or drop hammer; and when this is analyzed critically it resolves itself into a question of the time during which the work takes effect.

In the case of hydraulic press work, every molecule of the metal has ample time to transfer the push to its neighbors, and not much work is expended in internal friction. With a high velocity blow, however, there is little time for the transfer of energy and much work is expended in overcoming the high internal resistance, and is converted into heat. It is thus possible to have a job coming out of the dies at a considerably increased temperature.

Drop forgings can be classified under two headings, those of large area requiring maximum horizontal flow, and those in which the flow is mostly vertical. In the first case every inducement must be adopted to allow the metal to run away, such as highly polished die surfaces and ample lubrication. In the second case, where vertical flow is desired, it is necessary to create conditions to increase the resistance to horizontal flow, so that the plastic metal may be squirted or extruded into the unfilled die spaces. If the flat surfaces of the die are rather rough this will increase the frictional resistance which will be greatly reinforced when the fin begins to form. Another important factor is that work which is applied slowly (as by low velocity blows) is selective, having more time to search for

(*Continued on Page* 108)

Reviews of Recent Patents

1,447,356. Die Support for Wire-Drawing Machines. Charles H. Osland, Worcester, Mass., assignor to the O. & J. Machine Company, a corporation of Massachusetts.

This patent refers to a wire-drawing device, the combination with a bracket provided with a pair of upwardly extending sides, each perforated, a guide pin extending through each perforation in a direction parallel to the direction of the wire, said pins and sides being located at a distance apart, a spring on each of said guide pins bearing against said upwardly extending sides and a box for lubricant having ears on opposite sides provided with perforations through which said pins pass and having means for preventing the ears from being pushed off the pins, said springs bearing against said ears of a wire drawing die supported at the end of said box beyond the springs, said box having means by which the die is firmly secured in position and also provided with flanges oppositely located and engaging the surfaces of said upwardly extending sides opposite the springs, whereby the whole box with its die is yieldingly mounted and is guided to move with the wire or against it in parallel relationship to it at all times.

1,447,517. Automatic Temperature-Control Means for Electric Furnaces. Thomas Andrew Reid, East Orange, N. J., assignor to Electric Heating Appartus Company, Newark, N. J.

This invention refers to the combination with an electric furnace having a single source of electrical energy, of variable voltage contacts and a coacting switch arm to control the input to said furnace without interrupting the flow of current therethrough, a pyrometer having a movable contact element and spaced stationary contact elements of opposite sign, a motor to operate said switch-arm in either direction of its movement for varying the voltage of current supplied to the furnace, motor circuit including said pyrometer, and an independent source of energy for the control of said motor.

1,447,817. Art of Casting Metals. James M. Perry, Detroit, Michigan, assignor of two-thirds to himself and one-third to Horace G. Seitz, Detroit, Mich.

This patent relates to an art of casting metal for the production of castings of generally uniform cross-section in the direction of length of the casting, and wherein the casting is of a comparatively thin-walled type, the method of eliminating imperfections of the bubble or hold type therefrom which method consists in moving the imperfection sources from the poured metal to a waste zone by increasing the normal

speed of travel of the sources in the direction of natural movement thereof to an extent sufficient to carry the sources to such zone prior to solidification of the metal.

1,447,909. Welding Machine. James Hall Taylor, Oak Park, Ill.

This invention comprises the combination of heating apparatus for heating the work to be welded, welding surfaces between which the heated work is welded, and a one cycle stop mechanism operable to move the work between said heating apparatus and said welding surfaces.

1,448,388. Electric-Furnace Resistor. Ora A. Colby, Irwin, Pa., assignor to Westinghouse Electric & Manufacturing Company, a corporation of Pennsylvania.

This invention relates to the combination with a plurality of walls surrounding a furnace chamber, of a resistor in said chamber comprising a plurality of dished refractory electrical-conducting members, granular resistor material in each of said dished refractory members and resilient means for maintaining said dished members in interlocked position in said furnace chamber free of said walls.

1,448,480. Apparatus for Operating Furnace Doors. Lester D. Bedell, Bethlehem, Pa.

This patent refers to an apparatus for operating furnace doors which comprises the combination with a vertically movable door, of a movable lifting member connected thereto, and means for counterbalancing said door and for moving it through connection with said lifting member comprising a counter-weight of materially less weight than the door, differential operating and supporting mechanism connecting the end of said member and means in a fixed position for applying power to said operating and supporting means to cause movement of said door and counter-weight in either direction at different speeds.

1,448,684. Laminated Super-refractory Article. Milton F. Beecher and MacDonald C. Booze, Worcester, Mass., assignors to Norton Company, a corporation of Massachusetts.

This relates to a laminated refractory article having a facing of bonded refractory material, a reinforcing backing layer of ceramic material which is reactive with an ingredient of the facing, and a neutral intermediate layer intimately joined to and separating the facing and backing layers.

1,448,701. Forging Furnace. Harry O. Breaker, Winthrop, Mass., assignor to Industrial Furnace Corporation, Boston, Mass., a corporation of Massachusetts.

The above refers to a forging furnace which comprises a combustion chamber provided with a movable hearth above the combustion chamber, and with an adjustable longitudinal opening therein for the escape of the products of combustion.

News of the Chapters

BOSTON CHAPTER

The Boston chapter of the American Society for Steel Treating held a meeting on May 24th which was attended by about sixty members and guests. At this meeting the following new officers were elected for the ensuing year: chairman, H. E. Handy, vice-chairman, V. I. Homerberg, sec.-treas., G. E. Davis. The retiring chairman and secretary with the new officers will comprise the executive committee and it is felt that with a new start the chapter may be brought to the front.

CHICAGO CHAPTER

The Chicago chapter of the American Society for Steel Treating held a regular monthly meeting on May 10, at the City Club, 315 Plymouth Court. The speaker of the evening was E. W. Ehn, metallurgist, Timken Roller Bearing Co., who presented an illustrated talk entitled "Carburizing and Hardening Qualities of Steel as Influenced by Deoxidization of the Steel When Made." Mr. Ehn having made an exhaustive study of this subject gave much valuable information on the carburizing and hardening of steel, and a very lively discussion was participated in by the large number in attendance.

At this meeting the following members were elected to serve for the ensuing year: chairman, F. G. Wheeler, Miehle Printing Press & Mfg. Co., vice-chairman, R. G. Guthrie, Peoples Gas Light & Coke Co., secretary-treasurer, Arthur G. Henry, 1440 W. Lake St. The following executive committee was also elected: V. A. Hain, D. G. Haines, Wilbur Patrick, and W. H. Potter.

The chapter held its second annual outing on Saturday, June 9, at the Hartmann House, Wheeling, Illinois. The members were transported by automobile to Wheeling, where a chicken dinner was served to them at 2:30 p. m. The large

grounds of the Hartmann House was at their disposal and plenty of entertainment was provided. A most enjoyable afternoon was had by all.

CINCINNATI CHAPTER

The Cincinnati chapter of the American Society for Steel Treating held their June meeting on the 14th of the month. This meeting also included an inspection trip at 2.30 p. m. to the Pollak Steel Company. Dinner was then served at 6:00 p. m. at the Ohio Mechanics Institute, and the meeting followed at 7:30 at the same place. The paper of the evening entitled "The Impurities in Steel" was given by Dr. J. Culver Hartzell, chairman of the chapter. Dr. Hartzell gave many instructive points with reference to the impurities found in steel and a lively discussion followed.

An enjoyable afternoon and evening was spent by all.

At the chapter meeting held on May 10th, the following members were re-elected to serve on the executive committee: E. W. Detraz, Edward Gardner, C. H. Waldo, C. J. Wersel. W. R. Klinkicht was elected in addition.

DETROIT CHAPTER

At the chapter meeting held on May 29th the election of new officers was held and resulted in the following elections: chairman, J. M. Watson, Hupp Motor Car Co., vice chairman, W. P. Woodside, Studebaker corporation, secretary-treasurer, W. G. Calkins, Detroit Twist Drill Company. The following executive committee was also elected to serve for the coming year: Robert Atkinson, Halcomb Steel Co., Edmund Blasko, Ford Motor Co., H. G. Peebles, Detroit Steel Products Co., R. C. Banks, Maxwell Motor Co., W. E. Blythe, Driver-Harris Co., H. M. Northrup, Hudson Motor Car Co.

HARTFORD CHAPTER

At the May meeting of the Hartford chapter, the following members were nominated and elected to serve for the coming year: chairman, J. J. Curran, vice-chairman, C. M. Blackman, secretary-treasurer, L. A. Lanning. The executive committee is as follows: Chas. A. Allen, F. R. Downs, J. C. Kielman, R. F. V. Stanton, R. W. Woodward, and A. H. d'Arcambal.

INDIANAPOLIS CHAPTER

During the May meeting of the Indianapolis chapter the members of the chapter elected as their officers for the ensuing year H. B. Northrup, metallurgist with the Diamond Chain & Mfg. Co., as chairman and R. Robert Smith, of 1535 Naomi St., as secretary-treasurer.

J. M. WATSON
Chairman—Detroit Chapter

H. B. NORTHRUP
Chairman—Indianapolis Chapter

LOS ANGELES CHAPTER

The Los Angeles chapter of the American Society for Steel Treating held a meeting on Thursday, June 6th, at the offices of the Westinghouse Electric & Manufacturing Company, 418 South San Pedro Street, at 7:30 p. m. The speaker scheduled for this meeting, Mr. Harwood, was unable to attend, and consequently A. B. Denny, mill superintendent, Columbia Steel Corporation, presented a paper entitled "Open-Hearth Steel." Mr. Denny gave a very capable presentation and brought out

many interesting points about the manufacture of open-hearth steel. The entertainment committee was on hand and a very enjoyable evening was spent by all.

LEHIGH VALLEY CHAPTER

The Lehigh Valley chapter of the American Society for Steel Treating recently elected the following members to serve for the coming year: chairman, A. P. Spooner, vice-chairman, G. C. Lilly, secretary-treasurer, B. F. Shepherd. The executive

A. P. SPOONER
Chairman—Lehigh Valley Chapter

committee is as follows: W. H. Laury, W. R. Shimer, F. P. Martin, A. C. Moyer, S. P. Koch, H. S. Brainerd, A. E. Fowler, B. H. DeLong and R. H. Christ.

NEW HAVEN CHAPTER

According to reports from the New Haven chapter, the best meeting which the chapter ever held took place Friday evening June 15, 1923.

The meeting was held at the Wilcox Pier Restaurant, Savin Rock Park. This meeting was primarily for the purpose of having a good time. A shore dinner was served at 6:30 p. m. and all hands enjoyed a good old feed. The cabaret show and music were excellent, as was also the thoughts which were developed by the speaker, E. H. Webb, president of the Webb Wire Works, New Brunswick, N. J.

Everybody was out for a good time and thus added to the committee's efforts very materially in realizing a wonderful time.

Fred J. Dawless being considerable of a song writer introduced his version of Mr. Gallagher and Mr. Shean and the boys fell in line and enjoyed his efforts very much. His verses are as follows:

Mr. Gallagher and Mr. Shean

1

Oh! Mr. Gallagher, Oh! Mr. Gallagher
Hello, what's on your mind this morning Mr. Shean,
Ev'ry body's making fun
Of the way our country's run
All the papers say we'll soon live Eur-o-pean.
Why Mr. Shean, Why Mr. Shean
On the day they took away our old canteen
Cost of living went so high
That it's cheaper now to die,
Positively Mr. Gallagher,
Absolutely Mr. Shean.

2

Oh! Mr. Gallagher, Oh! Mr. Gallagher
Once I think I saw you save a lady's life,
In a rowboat out to sea
You were a hero then to me
And I thought perhaps you've made this girl your wife
Oh! Mr. Shean, Oh! Mr. Shean
As she sunk I dove down like a submarine
Dragged her up upon the shore
Now she's mine forever more,
Who, the lady Mr. Gallagher?
No, the rowboat Mr. Shean.

3

Oh! Major Hill, Oh! Major Hill
You're the finest singer we have ever heard.
Everybody says it's fine
When you sing "Sweet Adeline"
In a way that sounds exactly like a bird.
Oh! Major Hill, Oh! Major Hill
What is it that makes you sing so deep and full
Is it eating clams and fish,
Or some other tasty dish
Or perhaps it is a beverage
Won't you tell us Major Hill?

YES! We Have No Bananas

Yes! We have no bananas
We have no bananas today.
We've string beans and Hon-ions
cab-BAH-ges and scallions
And all kinds of fruit and say—
We have an old fashioned to-MAH-to
Long Island po-TAH-to
But YES! we have no bananas,
We have no bananas today.

YES! We have no steel troubles
We have no steel troubles today.
We once had a die break
It took weeks to make
But now that's all passed away
We have the good old Steel Treaters,
All good heavy eaters.
YES! We have no steel troubles,
We have no steel troubles today.

NEW YORK CHAPTER

At the New York chapter meeting held on May 16th the election of officers took place and the following have been elected to serve for the coming year: chairman, Sam Tour, metallurgist, Doehler Die Casting Company, Brooklyn, N. Y., vice-chairman, E. E. Thum, associate editor, *Chemical & Metallurgical Engineering,* New York City, secretary-treasurer, T. N. Holden, Jr., chief chemist, E. W. Bliss Company, Brooklyn N. Y. The following executive committee was also elected: P. D. Merica, International Nickel Co., New York City, W. B. Kopfer, Combustion Utlities Corp., Brooklyn, N. Y., K. B. Millett, Griscom-Russell Company, New York City, R. L. Angell, E. W. Bliss Company, Brooklyn, N. Y., H. J. Fischbeck, De La Vergne Machine Company.

The chapter held a meeting on June 20th at 8:15 P. M. in the Assembly Room of the Merchants Association of New York. The speaker of the evening was S. W. Miller, Union Carbide & Carbon Company, who chose for his subject, "The Application of the Oxyacetylene Torch to Heat Treatment." Mr. Miller gave a very capable presentation, dealing especially with the application of the oxyacetylene torch to the hardening and tempering of tools. Following the paper a lively discussion took place out of which many interesting and instructing points were developed.

The usual dinner was served at 6:30 p. m. in the Post Keller Restaurant.

PITTSBURGH CHAPTER

The Pittsburgh chapter of the American Society for Steel Treating held a meeting on Tuesday evening, June 5th at 8:00 p. m. in the Hawiian Room of the Wm. Penn hotel. The paper of the evening was presented by John M. Lessells, research engineering department, Westinghouse Electric & Manufacturing Co., who chose for his title "Some Remarks on Static and Dynamic Forms of Testing." Mr. Lessells presented his paper in a very capable manner, which brought forth a lively discussion.

PHILADELPHIA CHAPTER

The May meeting of the chapter was held on the 25th of the month at the Engineers' club.

The program for this evening consisted of a paper by Chas. E. Carpenter, president, E. F. Houghton & Co., entitled "What the Society Means to the Sustaining Member," and W. H. Eisenman, national secretary, spoke to the members on "What the Society Means to the Executive."

JOHN J. CROWE
Chairman—Philadelphia Chapter

At this meeting John J. Crowe was elected chairman and Arthur W. F. Green, secretary-treasurer for the ensuing year.

ARTHUR W. F. GREEN
Secretary-Treasurer—Philadelphia Chapter

PROVIDENCE CHAPTER

The Providence chapter of the American Society for Steel Treating held its regular monthly meeting on May 24, at 8:00 p. m., in the rooms of the Providence Engineering Society, 44 Washington Street. This meeting was in the nature of a round table discussion on problems of interest to all heat treaters, and proved highly satisfactory as the discussions brought out many instructive points.

The election of officers was held at this meeting, the chairman, F. H. Franklin, and the secretary-treasurer, W. H. Hunt, being re-elected, while I. E. Waechter was elected vice-chairman. An executive committee was also elected which consisted of the following members: F. N. Macleod, A. H. Annan, O. N. Geer, C. Peterson, and J. E. Wiggins.

ROCKFORD CHAPTER

At the Rockford chapter meeting held on May 18th, election of officers took place, at which time the following members were elected: chairman, Chas. Cotta, Cotta Gear Company, vice-chairman, G. Aldeen, National Locke Co., secretary-treas-

urer, J. B. Frederick, Barber-Colman Co. The executive committee consists of John Nelson, Martin Lundstrom, Arthur Memering, O. T. Muehlemeyer and R. M. Smith.

SOUTH BEND CHAPTER

The South Bend chapter of the American Society for Steel Treating held a meeting on May 9th at the Chamber of Commerce Building, at which time the following new officers were elected to serve for the coming year: chairman, Wm. J. Harris, first vice-chairman, W. F. Newhouse, second vice-chairman, V. R. Roberts, secretary-treasurer, Sam Shagaloff who was re-elected. The following executive committee was also elected: R. D. Allen, R. M. Holmes, J. A. Kingsbury, C. E. Ritchie, R. E. Lewton, and J. Nugent.

There were two papers presented at this meeting, the first being given by J. A. Kingsbury, entitled "The Selection of Tool Steels." The second paper was presented by C. P. Richter, who talked on "Oxygen and Steel." These two papers were very well presented and brought forth much interesting discussion.

SPRINGFIELD CHAPTER

The Springfield Chapter of the American Society for Steel Treating held its June meeting on the first of the month in the Chamber of Commerce Rooms, 47 Worthington Street. The speaker for this evening was R. J. Allen, Rolls-Royce Company of America, who chose as his subject "Steel from the Ore to the Finished Product." Mr. Allen brought out many interesting points and specimens of steel in the various stages of manufacture were shown.

The election of officers was held at this meeting and resulted in the following elections or re-elections: chairman, Edson L. Wood, Met., Springfield Arsenal, Springfield, Mass.; vice-chairman, V. T. Malcolm, Met., Engr., Chapman Valve Mfg. Co., Indian Orchard, Mass.; secretary-treasurer, E. L. Woods, Ind. Engr., Springfield Gas Light Company, Springfield, Mass., who was re-elected. The members of the executive committee are R. J. Allen, R. G. Robinson and F. R. Matthews.

SYRACUSE CHAPTER

The Syracuse Chapter of the American Society for Steel Treating held a meeting on Friday evening, May 25th at the Uhrig's Restaurant, which was attended by about 75 members and guests. The election of officers was held at this meeting which resulted in the following elections: chairman, F. C. Rabb, Brown Lipe Chapin Company; vice-chairman, F. A. Wheeler, H. H. Franklin Company, secretary-treasurer, R. L. Manier, Syracuse Lighting Company. The following executive committee was also elected: H. J. Stagg, Halcomb Steel Company, R. F. Smith, E. F. Houghton & Co., E. V. Clark, H. H. Franklin Company, J. C. Doty, Halcomb Steel Co., W. F. McNally, New Process Gear Corporation.

The usual dinner was served at the Yates Hotel preceding the meeting.

TORONTO CHAPTER

The Toronto chapter of the American Society for Steel held its regular monthly meeting on Friday evening May 25, 1923.

The speaker for this meeting was Prof. O. W. Ellis of the University of Toronto, who presented a very capable and interesting paper entitled "Some Mysteries of Steel Treating Simply Explained for the Practical Steel Treater." This paper brought forth many interesting points which proved to be of decided value to both the technical and practical men who had the privilege of hearing Prof. Ellis' address. Following the presentation a lively and interesting discussion ensued.

This meeting was the last one on the program for the year 1922-23.

TRI CITY CHAPTER

The Tri City chapter of the Society held its annual picnic at Linwood Resort, Iowa Shore west of Davenport, Saturday afternoon, June 23, 1923.

This picnic was certainly a decided success, there being the largest turnout for such an affair that had ever been held by the chapter. To be sure, the thermometer registered 96, but all members were on hand to enjoy the eats, drinks and smokes furnished by the chapter's picnic committee.

One of the main features of the picnic was a ball game between the Metallurgists headed by Put Putnam and the Tool Hardeners headed by C. U. Scott. The game was a good one but the Metallurgists succumbed to the Tool Hardeners, the score being 177 to 176. Everyone had a most enjoyable time and are looking forward to the next picnic a year hence.

In addition to the list of officers elected at the meeting of the chapter, as published in the June issue of TRANSACTIONS, the following members will serve on the executive committee for the ensuing year: Harold Brown, Reynolds Engineering Co., Moline, Ill.; C. H. Burgston, Deere & Co., Moline, Ill.; R. A. Heeschen, Zimmerman Steel Co., Bettendorf, Ia.; R. Henry, Moline Plow Co., Tractor Works, Rock Island, Ill.; J. F. Lardner, Deere & Co., Moline, Ill., and H. O. Koehler, White Lily Mfg. Co., Davenport, Ia.

WASHINGTON CHAPTER

The chapter held a meeting on May 25th at which time the election of officers for the coming year took place, the following members being elected: chairman, Jerome Strauss, vice-chairman, W. F. Graham, secretary-treasurer, J. S. Vanick. H. J. French was elected as chairman of the Meetings and Papers committee.

OBITUARY

It is with deep regret that we have to report the untimely death of John Everett Rogers, secretary of the A. Hankey & Co. Inc., of Rochdale, Mass. Mr. Rogers died the seventh day of May and in his death the Society lost an enthusiastic worker and friend.

Mr. Rogers was one of the early members of the Steel Treating Research Society, and was instrumental in the formation of the Worcester Chapter, in which he served faithfully as Secretary-Treasurer for two years and later as its Chairman. At the Indianapolis Convention "J. E." was chairman of the delegate's session and took an active part in the preparation of the program.

The enthusiam Mr. Rogers placed in his work, the cordial good will and ready assistance to all of the members and his

JOHN E. ROGERS

general capability endeared him to the members of the local chapter and to all people who were fortunate enough to have come in contact with him. He will be missed.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective

NEW MEMBERS

ACKER, SIDNEY A., (Jr-6), 1428 6th St., S. E. Minneapolis, Minn.
ADRIANCE, E. F., (M-5), 173 Santa Fe Ave., Huntington Park, Cal.
ALLAN, JAMES, (M-4), 1115 El Molino St., Los Angeles, Cal.
ARDAHL, EINAR, (Jr-5), 1907 16th St., Moline, Ill.
ARMOUR, JAMES D., (M-5), Union Drawn Steel Co., Beaver Falls, Pa.
ARNESS, W. B., (M-6), 2627 Nicollet Ave., Minneapolis, Minn.
ATKINS, CLARENCE B., (M-6), 129 Woodland St., Bristol, Conn.
AUSCHULTZ, L. T., (M-5), 1019 Blackadore Ave. E., Pittsburgh, Pa.
BAKER, CHAS. K., (A-6), 70 Mathewson St., Providence, R. I.
BELLIS, CLIFFORD B., (M-6), Blake & Valley Sts., New Haven, Conn.
BETTINGER, H. B., (A-6), 185 Devonshire St., Boston, Mass.
BICKNELL, ARTHUR B., (Jr-5), 2441 13th Ave., Moline, Ill.
THE BRISTOL CO., (S-6), Att: H. H. Bristol, V. P., Waterbury, Conn.
CHASE, RODNEY, (S-6), Chase Metal Works, Waterbury, Conn.
CLARK, RICHARD G., (M-6), New Departure Mfg. Co., Bristol Conn.
CLARK, WM. E., (A-6), Room 2-220 Gen'l. Motor Bldg., Detroit, Mich.
COLE, WILLARD W., (A-3), % So. California Iron & Steel Co., Los Angeles, Cal.
COLLINS CO., THE, (S-6), Collinsville, Conn.
COLWELL, DONALD L., (M-4), 5312 Pensacola Ave., Chicago, Ill.
COOLEY, W. S., (M-3), 1156 E. Calvert St., South Bend, Ind.
CRUM, B. M., (M-6), The Stanley Works, New Britain, Conn.
DALEMETER, VERNON, (M-5), Union Tool Co., Torrance, Cal.
DONNELLY, JAMES F., (M-5), 470 Vanderbilt Ave., Brooklyn, N. Y.
DULEY, W. H., (A-6), 1732 No. Adams Street, South Bend, Ind.
DUNBRACK, N. K., (M-5), 108 Alder Street, Waltham, Mass.
EDWARDS, W. H., (S-5), Edwards Iron Works, 2101 S. Main St., South Bend, Ind.
FICK, JOHN EDW., (M-6), Timken Roller Bear. Co., Canton, Ohio.
FURGASON, CLYDE A., (M-6), American Gear & Mfg. Co., Jackson, Mich.
FITZHUGH, JAMES M., (M-3), % Lewellyn Iron Works, Torrance, Cal.
FROMME, C. H., (M-4), 635 W. 35 Place, Los Angeles, Cal.
GEE, HARRY, (M-6), Dodge Brothers, Detroit, Mich.
GERMOND, R. C., (M-6), The Stanley Works, New Britain, Conn.
GOEDECKE, M., (A-6), 79 Woodruff Ave., Brooklyn, N. Y.
GOODYEAR, HARRY G., (M-4), 93 Richards Place, West Haven, Conn.
GRANGER, EDW. G., (M-6), 11 Sherman Street, Bristol, Conn.
HICK, GEO. H., (M-6), The Stanley Works, New Britain, Conn.
HULL, J. E., (M-4), P. O. Box 1318, Providence, R. I.
HUMPHREYS, E. T., (S-6), Seymour Mfg. Co., Seymour, Conn.
HYATT, M. V., (M-6), Fleetwood, Pa.
IRWIN, H. W., (Jr-4), 26 Villa Place, St. Thomas, Ky.
JACKSON, J. MILTON, (M-2), 1233 Lakewood Blvd., Detroit, Mich.
JOHNSON, JOHN, (M-6), The Whitney Mfg. Co., Hartford, Conn.
JOHNSTON, R. A., (A-3), Weherall Bros. Co., Albany St., Cambridge, Mass.
JOHNSON, WALTER L., (A-5), 420 So. San Pedro St., Los Angeles, Cal.

KUCHNEL, A. W., (M-5), 1429 E. Lombard St., Davenport, Iowa.
KYTE, HERBERT W., (M-4), 20 Carnegie Ave., East Orange, N. J.
LANDON, JUDSON P., (M-5), 72 Hart Street, New Britain, Conn.
LANTZ, WM. F., (M-5), 539 East North Street, Bethlehem, Pa.
LARSON, GODFREY, (M-12), 618 36th St., Rock Island, Ill.
LEETES, ERNEST, (M-4), 2514 Belvidere Ave., Detroit, Mich.
LOWMAN, M. C., (M-3), General Petroleum Corp., 2525 E. 37th St., Los Angeles, Cal.
THE MARLIN FIRE-ARMS CORP., (S-5), New Haven, Conn.
MARSH, L. S., (M-5), Inland Steel Co., 1st Natl. Bank Bldg., Chicago, Ill
McCHESNEY, CHAS., (M-4), 1409 Commonwealth St., Allston, Mass
MEAD, E. A., (M-5), 484 Beacon Street, Boston, Mass.
MOLINE BODY CORPN., (S-6), % Mr. L. F. Sickler, Moline, Ill.
NUSBAUM, J. E., (M-5), 1429 E. Marquette Rd., Chicago, Ill.
PARKER, FORREST S., (M-6), Saco-Lowell Shops, Lowell, Mass.
ROBBINS, M. T., (M-6), The Bellis Heat Treat Co., New Haven, Conn.
SCHIELE, GEO., (M-6), 3925 Forest Ave., Norwood, Cincinnati, Ohio.
SCOTT, CLIFFORD W., (M-4), 1510 1st Street, Rock Island, Ill.
SIMPSON, HARRY E., (M-6), 266 West Street, Bristol, Conn.
SOLOVIEFF, NICHOLAS, (Jr-5), Hastings St. & W. Cherry Lane, Baldwin, L. I., (N. Y.)
STANLEY WORKS, (S-6), New Britain, Conn.
STRATTON, SAMUEL S., (A-5), 102 Purchase St., Boston, Mass.
SULLIVAN, LEO D., (A-2), 4843 Bellevue Ave., Detroit, Mich.
TEUBER, CHAS. F., (A-3), Peoples Gas Lt. & Coke Co., 122 S. Mich. Ave., Chicago, Ill.
THELANDER, C. A., (M-2), 803 2nd Ave., Rockford, Ill.
THOMPSON, M. L., (Jr-5), 1164 22nd Street, Moline, Ill.
THURBER, ARTHUR E., (M-4), Oneida Community Ltd., Oneida, N. Y.
TRANTIN, JR. J., (M-6), % Pettibone-Milliken Co., 4710 W. Division St., Chicago, Ill.
TUTHILL, W. C., (M-5), National Machinery Company, Tiffin, Ohio.
WAGNER, JOHN, (M-1), 614 Genessee St., Flint, Mich.
WALKER, WM., (M-6), 91 Coburn Street, Lowell, Mass.
WEISE, ALFRED M., (M-6), 19 Wall Street, New Haven, Conn.
WETHERBEE, CHAS. F., (M-6), Marlin Fire-Arms Corpn., New Haven, Conn.
WILCOX, R. H., (A-5), 1482 Lee Place, Detroit, Mich.
WILLIAMS, ROBT. S., (M-5), Mass. Inst. of Technology, Cambridge, Mass.
WOODSIDE, ROBT. A., (Jr-4), 617 13th Avenue, Munhall, Pa.
ZIMMERMAN STEEL CO., (S-6), Bettendorf, Iowa.
ZINK, E. P., (M-4), 327 Mt. Vernon Ave., Detroit, Mich.

CHANGES OF ADDRESS

AFFLECK, G. S., from 278 E. Canfield Ave., to % Dodge Bros., Detroit, Mich.
ANDERSON, ARVID, from Pratt & Whitney Co., to 394 New Britain Ave., Hartford, Conn.
ARCHEA, WALTER D., from 621 Crown St., Cincinnati, O., to 2341 Kenilworth Ave., Norwood, Cincinnati, Ohio.
ARTHUR, WALTER, from Texas Christian Univ., Ft. Worth, Tex., to Reeds, Mo.
BECKER, CHAS. R., from 631 Canton St., to 3030 Collingwood Ave., Detroit, Mich.
BEDWORTH, R. E., from % Westinghouse Research Lab., E. Pittsburgh, Pa., to Westinghouse Elec. & Mfg. Co., 165 Broadway, New York, N. Y.

BLUMBERG, HARRY, from 1424 W. 14th St., Chicago, Ill., to 2414 Auer Ave., Milwaukee, Wis.
BLYTHE, W., from 1962 Tuxedo Ave., Detroit, Mich., to 412 Brookside Dr., Birmingham, Mich.
BOHNER, C. M., from 216 Myrtle Place to 143 Hall Street, Akron, O.
BOYLE, J. D., from Continental Motors Corpns., Muskegon, Mich., to 1131 Newport Ave., Detroit, Mich.
BRAY, H. M., from 324 4th Avenue, Pittsburgh, Pa., to Colonial Steel Co., 213 West Lake Street, Chicago, Ill.
BRUCE, Y. J., from 34 Chittenden Ave., Columbus, O., to 94 S. Linwood Ave., Crafton Branch, Pittsburgh, Pa.
BURROWS, C. W., from 17 Nevada St., Newark, N. J., to 154 Ogden Ave., Jersey City, N. J.
CLARK, REGINALD, from 175 Norwalk Ave., Buffalo, N. Y., to Western Drop Forge Co., Marion, Ind.
COLCORD, C. A., from 1951 W. Madison St., Chicago, Ill., to 623 Layton Ave., Cudahy, Wis.
COWELL, W. T., from 1851 Chase Ave., Cincinnati, O., to Reed & Prentice Co., Worchester, Mass.
CROSSMAN, L., from 285 Main Street, Bristol, Conn., to 15 Amherst, Springfield, Mass.
CROWLEY, D. J., from 823 Dime Bank Bldg., Detroit, Mich., to Wayne, Michigan.
DODGE, RALPH, from 810 Park Ave., Syracuse, N. Y., to 126 Peck Ave., Syracuse, N. Y.
DOERR, PAUL C., from 54 Meridith St., Springfield, Mass., to Kenwood Ave., Delmar, N. Y.
GREEMAN, O. W., from 24 Hendricks Place to 1933 College Ave., Indianapolis, Ind.
HICKOX, WILL, from 743 32nd Street, to 661 Jackson St., Milwaukee, Wis.
HILDORF, WALTER, from 521 E. Main Street to 532 Park Lane, East Lansing, Mich.
HOBBS, D. B., from 2210 Harvard Ave., to 3790 Archwood Place, Cleveland, Ohio.
JACOBUS, L. C., from Tate Jones & Co., Pittsburgh, Pa., to 808 Beaver Street, Sewickley, Pa.
JOHNSON, WM. R., from 134 Juneau Ave., Apt. "C," to 142 27th St., Milwaukee, Wis.
KURRASH, C. A., from 9828 Winston Ave., Chicago, Ill., to 92 Peterboro St., Detroit, Mich.
LARDNER, JAMES F., from John Deere Plow Works to 1729 11th Ave., Moline, Ill.
LOEBELL, H. O., from A. L. Doherty Co., 24 State St., to 8-10 Bridge Street, New York City, N. Y.
LOTTES, W. G., from Steel Expert Mfg. Dept., International Harvester Co., Harvester Bldg., Chicago, Ill., to 213 Lake Street, Madison, Wis.
McAMBER, M. F., from 6340 Douglas Ave. E., to 924 Maryland, E. Liberty St., Pittsburgh, Pa.
McGAHEY, W. E., from 105 Highland Ave., Covington, Va., to 1104 145th St., East Chicago, Ind.
McMILLEN, R. H., from 134 Virginia Ave., Aspinwall Sta., to 1115 King Ave., Pittsburgh, Pa.
MOHR, E. J., from 1903 Chambers St., to 757 27th Street, Milwaukee, Wis.
PENROD, W. W., from 1556 Cohassett Ave., Lakewood, Ohio, to % International Harvester Co., Milwaukee, Wis.

PERRY, L. C., from Scullin Steel Co., 6700 Manchester Ave., to 4950 Forest Park Blvd., St. Louis, Mo.
PFEIL, WALTER H., from Box 1103, East Chicago, Ind., to Standard Engr. Co., Elwood City, Pa.
RICHARDSON, G. A., from Midvale Steel Ordnance Company, 1630 Widener Bldg., to 27 E. Springfield Ave., Chestnut Hill, Philadelphia, Pa.
RIMBACH, RICHARD, from 327 McKee Place, Pittsburgh, Pa., to 244 East 30th St., New York City, N. Y.
ROHLAND, L. E., from Poldi Steel Corp. of America, 115 Broadway, to 151 Baick St., New York City, N. Y.
ROOT, H. H., from 146 33rd Street, Whitestone Landing, N. Y., to 126 Lathrop Street, Beverly, Mass.
SCHEID, A. J., Jr., from 707 Delaware Street, Minneapolis, Minn., to 634 28th Street, Milwaukee, Wis.
SCHULTZ, HARRY, from 728 15th St., S. E., Washington, D. C., to 1004 Braddock Ave., Swissvale, Pa.
SIEGMEIR, ALBERT, from 5717 S. Aberdeen Street, to 5837 Mozart Street, Chicago Lawn Station, Chicago, Ill.
STERNAGLE, C. A., from Colonial Steel Co., 213 W. Lake St., to 7011 Chappell Ave., Chicago, Ill.
THOMAS, C. P., from 1107 Lee Street to 910 Vine Street, Lansing, Mich.
WACKER, J. W., from % Chain Belt Co., to Sterling Tool & Mach. Co., Wilwaukee, Wis.
WILLIAMS, D. R., from 262 Palace Theatre Bldg., to 610 Sycamore St., Milwaukee, Wis.
WOODWARD, E. L., from 2201 Woolworth Bldg., to 30 Church Street, New York City, N. Y.
ZIMMERLI, F. P., from 459 Hancock W., to 1585 Delaware Ave., Detroit, Mich.

MAIL RETURNED

GLAB, PETER, 502 East Jefferson Street, Syracuse, N. Y.
PUSITZ, L., 3514 28th Street, Detroit, Mich.
WARD, W. J., Union City, Pa.
WOLF, ERNEST, Lewis Institute, Chicago, Ill.

QUESTION BOX

Concluded from Page 90

lines of weakness and cleavage planes, and consequently is more economical in the expenditure of energy. High velocity blows have just the opposite effect; the plastic steel presents a greater resistance to outward flow, and fills up the die from a smaller bar and with a smaller fin.

A word of warning may be given with regard to the dies. The effect of high velocity blows is likely to be more local, therefore deep impressions should have plenty of material around them.

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

TRANSACTIONS
of the
American Society for Steel Treating

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WAGES OR SALARY

IT IS quite frequently stated that the individual who receives wages has only a job, while he who receives a salary is considered to have in his possession a position. While the difference between a job and a position is of no degree of importance there is as a rule quite a wide and perceptible distance between wages and salary. For instance: a brick layer at $18.00 to $20.00 a day, a plasterer at a similar rate compare all to favorably with the skilled graduate engineer who must by force of circumstances and nonappreciation on the part of his employer go along on a salary of $200.00 to $250.00 a month.

We are always ready to grant the truth of the statement that the metallurgical profession is under paid. There are several prominent reasons that present themselves for this unfortunate and serious condition of affairs, the first of which is that metallurgy as a profession is rather new and consequently those employers of the old school are rather reluctant to grant the premises of a statement that a new profession has risen that performs a work of fundamental importance to his plant. The second reason for the small amount of the monthly pay check of the metallurgical engineer is that the engineer himself has failed to impress upon his employer the importance and responsibility of the position he fills.

On the books of any manufacturing concern you will find listed productive men and nonproductive men and it is unfortunate to observe that the metallurgical engineer is placed on the nonproductive list. Consequently, when it is possible for one of the production men to place a chart before the manager showing that they have been able to increase production on certain machines 50 to

75 per cent it all makes a very favorable and profound impression upon the manager while undoubtedly it was not brought to his attention that the reason for this splendid increase in the efficiency of the machine was due to the solving of a problem by the metallurgical department.

We believe in giving every man his just dues, and we feel quite confident that the metallurgical engineer has not received his just dues, and that it is up to the engineers themselves to maintain a cost system in their own department and to charge up as productive labor all problems that are solved by their department which in anyway add to the efficiency of production.

Too many of our members are accustomed to hide their light under a basket, and while shouting your own praises or tooting your own horns are conditions that do not meet with hearty approval, nevertheless there are certain activities that the metallurgist concerns himself with that should be presented in actual figures and facts before the management. It is perfectly proper the metallurgist should receive a salary comparable in all respects to the the important and responsible position he occupies.

WHITE COLLARS

CONTINUING the same line of thought as in the previous article, a large employer of labor recently stated his inability to employ men for responsible positions in the plant, while there was an over supply of white collared youths who were willing to take a clerkship at $50.00 a month that offered no possibilities of any great advancement. One would be able to point without any strenuous effort countless individuals who have risen to great prominence in the business world who had their beginning among humble surroundings and conditions, but who realized their opportunities at that time, were only stepping stones to greater progress.

One thing that can be said of the metallurgical profession is that while it has men of the highest type many with college training, it also has individuals who understand and are willing to shed their coats and buckle down to the exigencies of the occasion in which they find themselves.

At the recent close of the commencement exercises of

American colleges and universities, 30,000 graduates entered into the world of business. There are those who discount the advantage of a college education, and when one considers the earning power of a college graduate as compared with a man who has learned a trade, there is some basis for doubt. However, all realize that while money is a very desirable commodity and a necessity in all activities, nevertheless it should not be the goal for which one strives.

There is a condition in living by means of which under the most favorable circumstances one is permitted to enjoy and live in harmony with everything around him, and it is all brought about in a most happy combination of conditions. While the college trained man starts in the race under a handicap of less practical experience, nevertheless, he has a better equipped mind and is able to make more rapid progress than the man who lacks scholastic advantages.

In this connection, the LeFax editors have made a study of the average incomes for five years, of the earnings of the University of Pennsylvania graduates in which it is shown that the owner of a business has the largest income, and this emphasizes an important truth that the individual who usually obtains the greatest wealth is the individual working for himself and not for another. Salesmen, printers and life insurance agents, rank next to the owners of business as to the amount of renumeration received each year, while chemists and engineers are well toward the bottom of the list, and are listed at about $3000.00 per year. While there are no statistics on which we base any further deductions one is inclined to believe that as far as it applied to the metallurgical engineer, this amount is higher than the average pay received by technical graduates in this line. When one realizes the great responsibility and opportunity for service that is placed before the metallurgical profession there is no reason whatever, why the average income should not rank as high as that of any of the other worthwhile occupations.

An important responsibility rests on the members of this Society, the pioneers in the metallurgical industry, to so diligently devote themselves to their opportunities, to work so conscientiously in all of their undertakings, and then realize

that there is no law that forbids presentations to managers of important accomplishments in their department. All this then will have a tendency to increase the respect a manager should have for worthy calling and at the same time build up a higher standard of renumeration for work well done.

THE STORY OF A STEEL TREATER

THIS is the story of a steel treater, a true story, told to show how one of the many, just like you and I, was able to rise out of his mediocre surroundings and take enjoyment of that which we all seek—success.

A short few months ago this man was buried in a heat-treating room, carefully doing his daily work, at $25.00 per. He was approached by one of our enthusiasts and asked to join the American Society for Steel Treating. Ten dollars looked big to him with the family needing things, and besides he had heard that these Steel Treaters were getting *high-brow* and that they spoke a peculiar language at their meetings, that they were "different." But, he was made of the right stuff, so he joined.

He had not paid so much attention to the "why" of his job but his first contact with the Steel Treaters showed him that they were discussing the "why" part of his own job. He then recalled that their talk sounded very much like conversations he had overheard at the plant between the superintendent and the metallurgist from the *lab*, and that frequently, after such talks, he was told to do things a little differently. Then it dawned upon him. If a fellow understood such things he would get the better jobs. His "big boss" was a level headed business man and surely there was common sense in the thing.

Then another thing came to him. Here at these very meetings were those same "high brows," even the metallurgist from the *lab*. They were quite human and very likeable and seemed to take an interest in him, along with the awakened interest in himself. He attended every meeting and read the TRANSACTIONS and entered into the spirit of the Steel Treaters in full swing and became well acquainted with the metallurgist from the *lab*. Then

came the opportunity, for which he had unconsciously prepared himself. His friend, the metallurgist, you see got around to different plants and "knew things." There was an opening at one of the company's branch plants. They were doing a big business in a quality product and were looking for someone to work with the men and show them how—but this man must understand his job, he must know the "why," or else they could not use him. The metallurgist at the *lab* got him the job.

Then comes the conclusion. The $25.00 was doubled at once; instead of a job, he had a life's work; instead of routine work, he had diversity; instead of listening in, he was discussing things with the superintendent. Then he was given charge of the shop, and again his salary was raised. Now, he and his family, really know what it means to "get along" in the world, to have the association of fellow Steel Treaters and the value of finding out the "why." He also knows that he is made of the right stuff and that success really comes to those who are prepared for it. And he knows that the American Society for Steel Treating helped him prepare, gave him the start, and then placed Opportunity at his door, even as it can do for you and me.

S. L. H.

THE GEORGE SPOT

THE unique piece of research work performed by Harry S. George of the Union Carbide and Carbon Laboratories, Inc., described in detail in this issue of TRANSACTIONS, typifies the inventive genuous of our American metallurgists, chemists, and engineers.

Through the simple application of an opaque disk properly placed in the optical system of an ordinary bench-type metallographic microscope, Mr. George has made it possible to more minutely and accurately study the microscopic structure of metals, their grain boundaries and physical condition, in their true relationship to the actual condition of the object.

While this development seems a simple one and one which should have been discovered long ago, nevertheless it required much study and concentration on the part of the author. It

shows that he had that fundamental knowledge of the properties of light and lenses which, of course, would be indispensible in a research of this nature. Knowledge of the fundamentals involved in the study of any problem is of absolute importance, otherwise the investigator simply stumbles along in the dark and seldom arrives at any definite goal.

Mr. George's "spot" will undoubtedly aid many investigators in their researches on the theory and constitution of metallic alloys and the result of the use of this method may cause several changes in the theories which have thus far been advanced.

Through the use of conical illumination the work of the metallographist will become somewhat more pleasant since it is considerably more interesting and less fatiguing to view objects in their three dimensions rather than in only two dimensions, such as is the case in ordinary vertical illumination. Nonmetallic inclusions, grain boundaries, slip planes, etc., can now be studied from a somewhat different point of view, which should result in some worthy researches on this phase of metallurgy.

ON TO PITTSBURGH

WHEN keen minds get together, as they will in Pittsburgh during the second week in October, it behooves all of the members of the A. S. S. T. to make plans immediately to be present at the conferences during the Annual Convention of the Society. The Annual Convention and Exposition are looked forward to, as making epochs in the progress of the association, and in the advancement of the arts and sciences connected with the manufacturer or treatment of metals.

The 1500 members of the Society who attended the conference last year, at Detroit, will need no special urging or inducement to impress them with the great importance and vast amount of valuable information that is to be obtained by attending a convention. It is only to those individuals who have never attended an annual A. S. S. T. get-together that there is need to have brought home very forcibly the great loss that will result to them in not having attended.

In speaking of the Convention last year, the *Iron Age* reported:

> "An unqualified success was the general verdict of those who attended the fourth annual Convention and Exposition of the A. S. S. T. The record made by this Society, only three years old, both in technical papers and in exhibits, insures it a place among the leading technical organizations in the country and stamps its annual meeting as one to the looked forward to and to be reckoned with."

The Iron Trade Review stated:

> "Probably the widest representation of the iron and steel industry ever witnessed in this country was assembled at the fourth annual Convention and Exposition of the A. S. S. T."

Chemical and Metallurgical Engineering said:

> "Steel Treaters have done something which is perhaps unparalleled in the history of American technical societies. They have held a National Convention at which 40 per cent of their entire members enrolled was present. They were rewarded by the best meeting and exposition the A. S. S. T. has ever had."

The chairman of the meetings and papers committee has arranged in co-operation with the other members of the committee a program of papers, round tables and symposiums so that this session will mark a great advancement in metallurgical knowledge. While it is true that all the papers and discussions will be printed in the TRANSACTIONS, nevertheless the advantage of hearing them presented by the author, of being able to participate in the discussion and to ask questions upon points that do not present themselves at the time with sufficient clearness, all combined to make hearing a paper more valuable than reading it.

The hearing of papers read and discussed, is one of the important advantages to be obtained by attendance, yet the fact that you are brought into personal contact with the leading metallurgists and manufacturing executives of the coun-

try, is of importance. The opportunity to meet them and discuss with them your problems adds to the wonderful advantages to be obtained.

It is needless to call especial attention to the great educational value of the exhibits. There will be gathered together at Motor Square Gardens during the week of October 8th to 12th, the most imposing number of leading experts in the manufacturing of metals, metal-working machinery, supplies and appliances for metal treatment it will ever be possible for you to meet and talk with during the year.

When you consider that any problem you may have could quite easily be solved by conference with any one of these highly specialized individuals, and that you have hundreds with whom you may discuss your needs, you should not hesitate a moment in making your preparations to attend the Convention and Exposition.

Thousands are availing themselves of this opportunity presented annually by your Society and it is incumbent upon you to realize that that which is of benefit to others would certainly be of great value to you. If you have not as yet presented the subject of your attendance at Pittsburgh to the executive in the plant, it is time now to present the benefit that is to be obtained by attending the Convention and Exposition. Not only secure permission for your own attendance but bring the plant executives with you.

Again the railroads of the country have granted fare and a half for the round trip, and certificates entitling members and their families to this reduction will be mailed from the Society's headquarters about the first of September. Members of the Society can write to headquarters and secure certificates for individuals who plan to come to Pittsburgh to participate in the activities of the week.

While the social side of the Convention has not been emphasized, you may depend upon it that the previous reputation for highly enjoyable occasions will be continued at Pittsburgh. The various committees under the leadership of J. Trautman Jr., are exerting themselves to the highest degree of endeavor, in order that those who attend will not only enjoy the technical and inspirational side of the convention,

but will carry back home with them the idea that Pittsburgh has a real friendly and hospitable spirit. Not only have they made extensive preparations for the entertainment of the members and guests of the Society, but they have also made intertesting plans for the entertainments of the ladies.

It is really important that you should begin your plans at once and make your hotel reservations from the list published in this issue of the TRANSACTIONS. As a member you should extend a cordial invitation to attend to all individuals, whom you feel would in any way profit by the Convention and Exposition.

HOTEL RESERVATIONS FOR THE CONVENTION

In order that our members and guests may be well taken care of during the time of the annual convention in Pittsburgh, October 8 to 12 inclusive, we are again publishing the list of the hotels at Pittsburgh so that you may make your reservations immediately and thus be sure of accommodations.

In writing to the hotel please state the price and kind of room you wish, and request them to acknowledge your communication confirming the reservation and price.

In case you have difficulty in securing the accommodations you wish, a communication addressed to the chairman of the hotels committee, R. E. Polk, chief industrial engineer, Equitable Gas Co., Pittsburgh, Pa., will receive prompt attention.

List of Pittsburgh Hotels

William Penn

(Headquarters)

375	Rooms	with	bath,	2	persons,	Rate	$3.50-5.00 each
375	Rooms	with	bath,	1	person,	Rate	4.00-8.00

Fort Pitt

190	Rooms	with	bath,	2	persons,	Rate	$2.50-5.00 each
100	Rooms	without	bath,	2	persons,	Rate	2.50 each
190	Rooms	with	bath,	1	person,	Rate	3.50-9.00
100	Rooms	without	bath,	1	person,	Rate	3.00

Hotel Henry

12	Rooms	with	bath,	4	persons,	Rate	$2.50 each
12	Rooms	with	bath,	2	persons,	Rate	3.00 each
24	Rooms	with	bath,	1	person,	Rate	4.00 up

WILLIAM PENN HOTEL
Convention Headquarters

Anderson Hotel

20	Rooms with bath,	4 persons,	Rate	$2.50	each
24	Rooms without bath,	4 persons,	Rate	2.00	each
10	Rooms without bath,	2 persons,	Rate	2.50	each
20	Rooms without bath,	1 person,	Rate	3.00	

General Forbes

17	Rooms with bath,	4 persons,	Rate	$2.00	each
9	Rooms with bath,	2 persons,	Rate	3.00	each
24	Rooms without bath,	2 persons,	Rate	1.50	each
25	Rooms with bath,	1 person,	Rate	4.00	up

Seventh Avenue Hotel

14	Rooms with bath,	4 persons,	Rate	$2.50-3.00	each
10	Rooms with bath,	2 persons,	Rate	2.50-3.00	each
20	Rooms without bath,	2 persons,	Rate	2.00-2.50	each

Pittsburgh Natatorium

(For gentlemen only)

175	Rooms, with swimming pool, cots, 1 person.	Rate	$2.00		

Monongahela House

10	Rooms with bath, 2 persons,	Rate	$3.00		each
40	Rooms without bath, 2 persons,	Rate	2.00		each

Schenley Hotel

5	Rooms with bath, 4 persons,	Rate	$3.00		each
10	Rooms with bath, 2 persons,	Rate	4.00		each
10	Rooms without bath, 2 persons,	Rate	3.00		each
10	Rooms with bath, 1 person,	Rate	7.00		
10	Rooms without bath, 1 person,	Rate	4.00		

Rittenhouse Hotel

25	Rooms with bath, 2 persons,	Rate	$2.00-3.00		each
20	Rooms with bath, 1 person,	Rate	3.00-4.00		

Y. M. C. A., East Liberty

10	Rooms without bath, 1 person,	Rate	$2.00		

Negri Hotel

25	Rooms with bath, 1 person,	Rate	$3.00		

New Sixth Avenue

15	Rooms with bath, 2 persons,	Rate	$3.00-4.00		each
15	Rooms without bath, 2 persons,	Rate	2.50-3.00		each
10	Rooms with bath, 1 person,	Rate	3.00		
5	Rooms without bath, 1 person,	Rate	2.00-3.00		

Chatham Hotel

5	Rooms with bath, 4 persons,	Rate	$2.00		each
20	Rooms with bath, 2 persons,	Rate	3.00-5.00		each
20	Rooms without bath, 2 persons,	Rate	2.50-3.00		each
15	Rooms with bath, 1 person,	Rate	3.00		

MEMBERSHIP AND ATTENDANCE CONTEST

THE Membership and Attendance Contest that has been in action during the past year, came to a close on June 30 with the following results:

First Prize	$200.00	Tri City	127.6 %
Second Prize	150.00	South Bend	99.3 %
Third Prize	100.00	New Haven	85.8 %
Fourth Prize	50.00	Cincinnati	65.5 %

The nearest to Cincinnati was North West with 56.4 per cent and Syracuse with 55.5 per cent. The standing of the other chapters in the contest was as follows:

	Per Cent		Per Cent		Per Cent
5. North West	56.4	9. Hartford	49.5	13. New York	31.7
6. Syracuse	55.5	10. Providence	47.9	14. Washington	26.2
7. Detroit	52.8	11. Milwaukee	38.8	15. Cleveland	25.7
8. Philadelphia	49.6	12. Rockford	38.6	16. Springfield	25.4
		17. Pittsburgh	18.9		

It is quite evident from the number of chapters participating in the contest that it has been very interesting and helpful, however, as the contest progressed it was observed that the smaller chapters had a certain advantage over the larger chapters, inasmuch as it required a smaller number, not only of new members but of those in attendance at meetings, to give a higher percentage.

While in actual figures Detroit has had the largest number of new members added to its roll nevertheless it had a low per cent of increase due to the fact that its increase was based on a larger original number. However, no credit is to be removed from those chapters that have so strenuously persevered to the goal throughout the entire year.

It is interesting to note that the progress of the Tri City and South Bend chapters has not been spasmodic but has been consistent throughout the year, and while with New Haven and Cincinnati the growth has been more or less steady, nevertheless both of these chapters sprang into prominence and high position toward the close of the contest by means of special activities on the part of individuals of their chapter and their membership committees.

THE ANNEALING OF SHEET STEEL

By Francis G. White

Abstract

In this paper the annealing of low-carbon sheet steel is discussed from the mill standpoint, and grain growth caused by a slow cooling rate from the annealing temperature is shown in photomicrographs. The complexity of sheet steel annealing will be realized when it is recalled that at times as many as 40 tons of sheets are placed in one furnace. The heat must be driven through an annealing cover and a blanket of air or gas surrounding the sheets, and then equally distributed throughout a mass of steel, probably three or four feet thick. While at this temperature as much air as possible must be excluded and the material cannot be exposed to the air until it is cool, otherwise, severe scaling of the sheets results. Slow cooling from this temperature is ideal for grain growth. If the sheets were heated to the upper critical range it would be impossible to open them because of "sticking," even though the cooling time could be shortened. Various furnace designs, temperature curves, and stamping tests are included in the paper and an outline of the general practice in one plant is discussed.

Introduction

GENERALLY speaking the requisites necessary for the successful annealing of sheet steel are, minimum grain growth, the removal of rolling strains, ease of opening after annealing, and a clear surface on the sheet. The cost of obtaining these qualities must of course be no higher than the trade will stand. To the user of sheet metal for stampings, the annealing is very important. While tin plate is not ordinarily thought of as a stamping steel, tin cans require double seaming, while

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A paper to be presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, Francis G. White, is metallurgical engineer with the National Enameling and Stamping Co., Granite City Steel Works branch, Granite City, Illinois. Written discussion of this paper is invited.

the tops and bottoms are light stampings. Galvanized sheets are very seldom stamped except when tite coated, but the trade seems to require a soft sheet whether it is blue, black, galvanized or tinned.

The various types of annealing furnaces, fuels, and methods of handling sheets and boxes are discussed. Certain annealing tests conducted by the author involving furnace design, fuels, etc., are incorporated in the text of this paper.

Box Annealing Furnaces

The fuels used may be either oil, gas, coal or electricity, while the furnace type may be the box, continuous box, or the continuous muffle. A furnace is usually built for one certain fuel, but probably with some rearrangement it could be adapted to more than one. The newer continuous box type furnaces are more or less in the experimental stage although numerous installations are giving great success. The old box types are the more common and are fired by either oil, gas, or coal. The first two of these fuels have a tendency to burn the sheets rather than anneal them, and the number of stickers is quite liable to be more pronounced. Two types of box furnaces are shown in Figs. 1 and 2, and after a trial on oil and gas were finally fired with coal screenings through automatic stokers, with fairly good success. Fig. 1, is a side-fired furnace while Fig. 2, is rear-fired. The problem of heat distribution within these furnaces had to be carefully studied before any set annealing practice could be followed. Sliding dampers on the flues, flues of various sizes, the height of the bridge wall varied, a recuperative bridge built, and the benches redesigned to allow the circulation of draft below the box, were some of the variables encountered.

Most of the tests described in this paper were run using one certain sized bottom and cover as shown in Fig. 3, with four such boxes charged into each furnace.

In the furnaces described, it was customary to pile the sheets as high as the cover would allow, this being about 42 inches, making the weight of sheets in each box vary from 10,000 to 16,000 pounds, depending of course on the size of the sheets.

On first thought it would appear that a uniform temperature throughout the furnace would be ideal, but when it comes to annealing many different sizes of sheets, a nonuniformity is at times

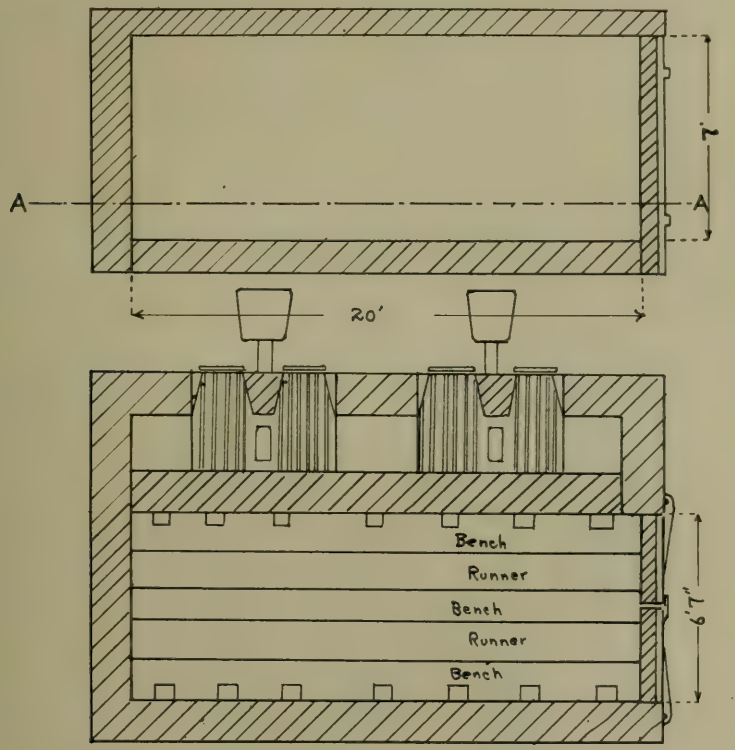

Fig. 1—Side-fired Double Stoker Box Type Annealing Furnace. Lower Sketch is Section AA Showing Flues. Upper Sketch Half Longitudinal Section.

advantageous because a heavy box of large sheets could be placed in the hottest portion of the furnace and the lighter boxes nearer the door. The actual practice, involving temperature and time will be discussed later in this paper under the heading of the various grades of steel, such as tin plate, deep stamping metal, etc.

Pyrometric equipment was installed, two thermocouples in the side-fired furnaces and one in the rear-fired. Rare metal

couples were used and an indicating instrument for the operator with recording instruments in the superintendent's office were supplied. It must be remembered that these instruments merely give the roof temperature of the gases and not the temperature

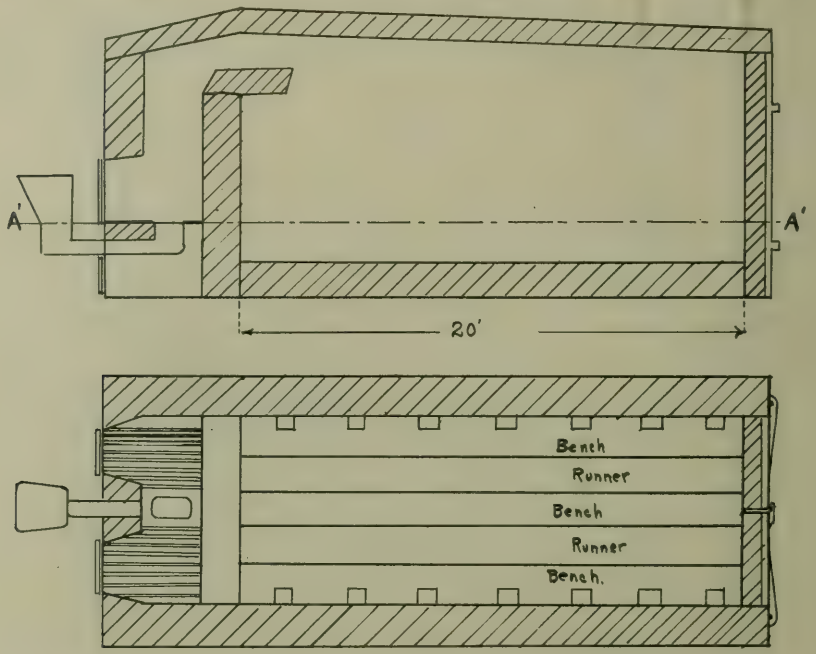

Fig. 2—Rear-fired Single Stoker Box Type Annealing Furnace. Lower Sketch is Section A^1A^1, Showing Flues. Upper Sketch Half Longitudinal Section.

of the steel within the box. The relation of the temperature of the steel to the roof temperature was carefully determined on several hundred boxes. In this annealing, the time element was found to be an important factor to be considered, because the air space within the cover is a very poor conductor of heat. To obtain the actual temperatures within the boxes by pyrometers requires quite an added expense on routine work so that when a set practice was adopted this equipment was no longer used. By observing the roof temperature reading, and applying the time factor, a fairly accurate figure for the temperature within the box could be estimated. Fig. 4 shows the arrangement of the thermocouples as they were set within the boxes. Iron con-

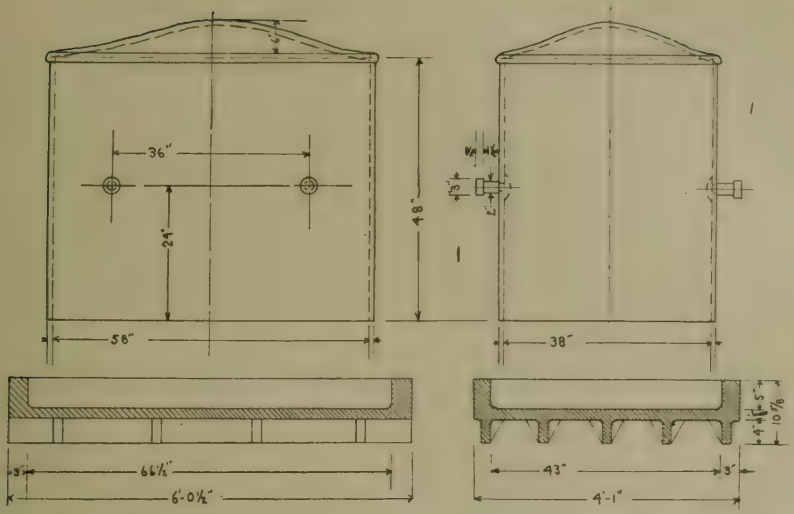

Fig. 3—Small Size Annealing Cover and Bottom Cover Weight—3300 Pounds. Bottom Weight—3250 Pounds.

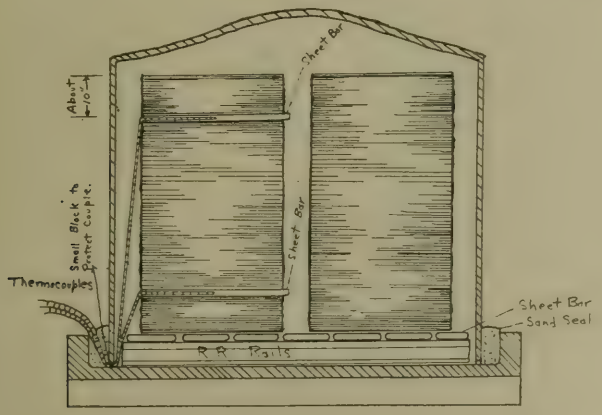

Fig. 4—Cross Section of Annealing Box Showing Method and Position of Inserting Thermocouples.

stantan couples were made up, each wire being covered with clay insulators, and the temperatures read with a potentiometer type pyrometer. The longest couples were about thirty feet, being used on the back boxes, while the others were shorter. In packing the sheets two ⅝-inch sheet bars were placed in the pile one or two inches apart, the bottom ones about ten inches from the

bottom and the top ones a similar distance from the top. By inserting the couple so that the junction was in the middle of the pile, then leading the couple under the cover and piling sand around the bottom, an air seal was effected. The boxes were then run into the furnace and the couples were lead out under the door, where they were connected to a multiple point switch, so that the reading time was quite rapid. Ordinarily, the reading was stopped when the temperature on all couples began to fall, which was often several hours after the boxes had been removed from the furnace. These thermocouples rarely lasted over five heats, so for regular practice the expense was far too great.

On several occasions there was a decided rise in the temperature readings several hours after the boxes had been removed from the furnace and at a time when the temperature curve showed a uniform drop for several hours. This may be a new critical range and always occurred around 900 degrees Fahr. No further discussion of this peculiar action will be taken up in this paper, because the author has not enough data at hand to say much about it. This condition may look like a pyrometric misreading, as there seemed no justified cause for it. While speaking of temperature readings it might be well to say, that in all this work the cold end was compensated by junction boxes in small wells surrounded by circulating water under a constant temperature of 75 degrees Fahr., and for roof temperature work rare metal couples were used. While pyrometers, without a doubt, are very helpful to both the annealer and the superintendent, who can thereby check his work, there is nothing more harmful to "the man at the fire" than an inaccurate or unreliable instrument.

Furnace Charging Methods

Concerning the methods of charging box annealing furnaces, two types might be considered. The cannon ball type, where the bottom is placed on several iron balls of about eight inches in diameter, has a great advantage, inasmuch as it allows a greater circulation of heat around or beneath the box. This method, however, makes charging much more difficult and is quite liable to warp the bottoms of the boxes. When benches are used, the boxes are placed on a jack or charging machine and pulled or

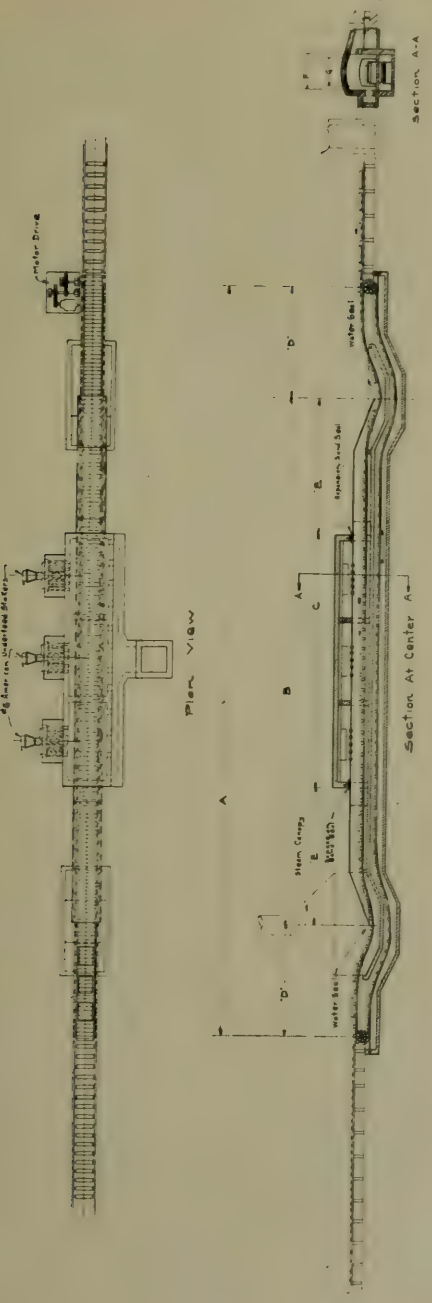

Fig. 5—Continuous Muffle Annealing Furnace for Sheet Steel Annealing. This Furnace Would Eliminate the Heating of Bottoms and Covers of Boxes.

pushed into the furnace. Here the bottoms are supported in many places and warping is less common. The bottoms are cast with fins which allow some circulation beneath them.

Continuous Box-Annealing Furnace

Undoubtedly the continuous furnace has some advantages over the stationary type, but there is still the necessity of expending a great deal of heat in heating the cover and bottom. At times this dead weight may exceed the weight of the sheets themselves. In this type of furnace the box is placed on a continuous belt or chain and carried through the furnace. By varying the speed of the chain a somewhat better control of heat is obtained over the stationary type of furnace.

Continuous Annealing In Muffle Without Boxes

While the author does not know of anyone using a continuous muffle furnace, without the use of covers or boxes, and in which is maintained a reducing atmosphere, nevertheless such a furnace has many commercial possibilities. Fig. 5 shows the plan and elevation of such a furnace. It would eliminate the heating of bottoms and covers and except for the continuous chain and the furnace losses, all the heat expended would go directly into the material to be annealed. The sheets could be piled a few inches high, instead of forty or fifty as is common, thereby enabling the material to pass through the heating zone rapidly, cooling much more rapidly, and cutting the annealing time from approximately sixteen hours to an hour or two, or perhaps less. The temperature at which the sheets would stick could be obtained and then the furnace temperature not allowed to run over it.

Stamping Qualities of Sheets

In box work, it is quite necessary to have an air-tight cover inasmuch as a leaky one will produce red or black sheets, burnt edges, or dirty surface. Lifting a cover too soon will give somewhat the same effect, and numerous customers believe that a sheet with well blued edges is a sign that it has been well annealed, while

in reality every box of steel could have a blue edge if it were allowed to get the air too soon.

Steel sheets are frequently deoxidized in annealing, i. e., annealed in a box in which the entrapped air is displaced by a nonoxidizing gas—and the resulting sheets are silvery white, with no trace of scale on them. Such a furnace as described would merely make the muffle an annealing cover, and since the cover method will work satisfactorily, the installation of a conveyer in a muffle is only a matter of mechanical arrangement. The blue annealing in an open furnace is a good example of rapid annealing, and on tests on similar gage box-annealed, the blue annealed sheets were much softer and stamped better.

Before taking up the furnace curves and actual temperatures used in these tests, the stamping qualities of sheets will be considered. While softness is usually the quality referred to, it seems an inaccurate way of expressing the stamping qualities, for an over-annealed sheet, exhibiting a large grain structure, will be dead soft if tested with any type of hardness te-ter, and a rough sheet will usually test softer than a highly polished one. The Erichsen testing machine, which seems to be the adopted standard for stamping tests, will show the stamping qualities quite clearly. In operation this machine holds a strip or square of about three inches in width, tightly against a die which has a circular opening in it which is approximately one inch in diameter. A rounded plunger on a screw is tightened up against the sheet and when a crack appears, the depth of impression is read on a gage. The relation of the sheet thickness and the depth of impression can be compared to a standard curve and expressed in percentage of the standard.

If we cut a diagonal across a sheet and take five or seven readings across this diagonal, and then find that the highest readings are near the edges, then we can say that the sheet is under-annealed, because the heat has not had time to penetrate to the middle of the pack. If the middle test gives the highest reading and the edges are low, then the edges have been at a high temperature for a sufficient length of time to allow grain growth. Photomicrographs have shown this to be true.

Dirty sheets, or those with a red surface or edges, have often been referred to as under-annealed, because in the stamping

operations the breakage runs high. Erichsen tests on such stock usually run up to standard because the machine runs quite lowly and friction is low. In rapid stampings, this scale acts as an abrasive on the dies and in turn tears the metal. Therefore, the surface condition is very important. A polished or cold rolled sheet will stamp better than a simple pickled and annealed one. Because of the strains set up, cold rolled material is usually re-annealed, but even then the grain structure is poor, and the added stamping qualities certainly relate to the surface. The exact ratio of these two factors is not known, but the fact that they are important seems quite evident.

Chemical Composition of Sheets

The chemical composition of the steel has purposely been avoided up until this time. This paper considers only a low carbon open-hearth steel of about 0.10 per cent carbon, about 0.035 per cent sulphur, about 0.40 per cent manganese and phosphorus varying according to the purpose, use and gage of the sheet. Light gage, such as tin plate, will run around 0.080 per cent phosphorus while heavier gage may run as low as 0.005 per cent. Since practically all stampings are made cold, and phosphorus imparts cold-shortness to the steel, we may say that the lower the phosphorus, other things being equal, the better the steel for stamping, here again, there may be an exception in that low phosphorus will not give the surface to the finished sheet, and as has already been mentioned, the surface is very important. Also the very low carbon or iron sheets do not stamp as well. No study as to the reason for this has been made as yet.

Laboratory Study of Annealing

A steel having a carbon content about 0.10 per cent, would have a theoretical annealing temperature near 1620 degrees Fahr. If a pile of sheets were heated to this temperature it would require a hammer and wedge to get them apart. Then too, because of the large mass of material and the slow rate at which it cools, there is ample time for grain growth. Hence, a test was made as follows. Six sheets were chosen with no special attention given to their selection other than to secure a considerable

Table I

Erichsen Tests

Summary of Results

Test No.	T—Thickness of Sheet / D—Depth of Impression											
	Steel A 18 Gage		Steel B 18 Gage		Steel C 20 Gage		Steel D 22 Gage		Steel E 27 Gage		Steel F 30 Gage	
	T	D	T	D	T	D	T	D	T	D	T	D
1. Heated to	1.42	9.52	1.33	9.25	.90	8.48	.76	6.40	.43	6.00		
1100°F.	1.39	9.30	1.33	9.58	.93	8.75	.77	6.61	.43	5.98		
cooled	1.37	9.65	1.31	8.84	.93	8.62	.77	6.70	.44	4.90		
slowly	1.37	9.58	1.33	9.32	.91	8.82	.79	6.68	.43	5.08		
	1.37	9.00	1.31	9.27	.92	8.70	.76	6.72	.43	5.15		
Average		9.41		9.25		8.67		6.62		5.42		
2 Heated to	1.38	10.50	1.34	9.77	.95	9.00	.78	7.01	.43	7.20	.31	6.07
1100°F. held	1.39	10.35	1.33	9.90	.94	9.13	.79	6.97	.42	7.15	.30	5.38
for 18 hrs.	1.38	10.25	1.33	10.15	.95	9.14	.81	7.47	.43	6.85	.32	6.23
cooled	1.38	10.24	1.30	9.80	.93	9.08	.79	7.36	.42	7.18	.29	5.72
slowly	1.40	10.10	1.34	10.10	.92	9.05	.78	7.50	.42	7.40	.31	6.38
Average		10.29		9.94		9.08		7.26		7.16		5.96-
3. Heated to	1.38	10.65	1.31	10.40	.93	9.23	.78	7.14	.43	7.25	.32	6.10
1200°F.	1.35	10.15	1.32	9.85	.92	9.00	.79	7.75	.42	7.00	.32	5.90
cooled	1.37	10.45	1.33	10.15	.93	8.92	.78	7.65	.43	6.97	.32	5.65
slowly	1.36	10.28	1.32	9.80	.94	9.30	.78	7.66	.42	7.25	.32	6.98
	1.36	10.25	1.33	9.90	.95	9.00	.76	7.40	.43	6.50	.32	6.85
Average		10.35+		10.02		9.09		7.52		6.99+		6.30-
4. Heated to	1.37	10.20	1.34	10.70	.93	9.18	.78	8.16	.42	7.53	.32	6.80
1200°F.	1.40	10.68	1.28	10.40	.95	9.95	.76	7.80	.43	7.58	.31	6.94
held 16 hrs.	1.38	10.85	1.31	10.45	.92	9.52	.79	8.16	.42	7.41	.32	6.70
cooled	1.37	10.50	1.31	10.40	.93	9.36	.79	7.95	.42	7.66	.32	7.05
slowly	1.39	10.50	1.32	10.37	.92	9.25	.77	7.67	.43	7.93	.30	6.46
Average		10.54+		10.46		9.45		7.95		7.62		6.79
5. Heated to	1.36	10.35	1.36	9.91	.96	9.27	.80	8.05	.43	7.32	.31	6.84
1300°F.	1.37	10.05	1.32	10.27	.94	9.18	.79	8.10	.42	7.34	.31	6.53
cooled	1.37	10.35	1.33	10.20	.92	9.45	.77	7.90	.42	7.00	.31	6.87
slowly	1.38	10.60	1.32	10.27	.92	9.20	.80	8.22	.42	6.28	.31	6.23
	1.35	10.55	1.31	10.30	.94	9.52	.78	7.85	.43	7.57	.31	6.45
Average		10.38		10.19		9.32		8.02		7.10		6.58
6 Heated to	1.36	10.65	1.32	10.17	.95	9.15	.78	7.95	.42	7.23	.32	6.60
1300°F.	1.36	10.46	1.29	10.34	.94	9.30	.79	8.25	.43	7.32	.32	6.32
held 16 hrs.	1.36	10.50	1.33	10.49	.93	9.45	.78	7.80	.43	6.67	.32	6.20
cooled	1.37	10.44	1.33	10.07	.94	9.12	.77	8.48	.43	6.50	.31	6.52
slowly	1.36	10.40	1.33	10.05	.94	9.42	.77	8.40	.43	7.75	.30	6.47
Average		10.49		10.22		9.29		8.18		7.09		6.42
7. Heated to	1.37	10.15	1.29	10.10	.94	9.25	.78	7.78	.43	7.23	.31	6.55
1400°F.	1.38	10.04	1.33	10.10	.95	9.00	.78	7.38	.41	7.45	.31	6.40
cooled	1.38	10.40	1.30	10.10	.91	8.99	.77	8.10	.43	7.05	.31	6.27
slowly	1.38	10.40	1.31	9.60	.95	9.00	.79	7.50	.43	7.37	.31	6.84
	1.36	9.90	1.31	9.88	.94	8.70			.43	7.07	.31	6.40
Average		10.18		9.96-		8.99		7.69		7.23		6.49
8. Heated to	1.37	10.47	1.33	10.65	.95	9.05	.78	8.95	.43	6.35	.29	6.10
1400°F.	1.39	10.49	1.33	10.71	.94	9.20	.78	8.25	.43	7.50	.31	6.03
held 16 hrs.	1.37	10.55	1.32	10.35	.94	8.50	.77	7.80	.43	7.30	.29	6.41
cooled	1.37	10.50	1.28	10.10	.93	8.66			.42	7.58	.31	6.20
slowly	1.37	10.55	1.32	10.40	.92	9.10			.42	7.28	.31	6.30
Average		10.51		10.44		8.90		8.33		7.20		6.21
Erichsen Standard Deep Stamping Steel	1.37	10.74	1.32	10.63	.93	9.67	.78	9.28	.43	8.12		
Tin Plate Steel									.43	7.65	.30	6.96

Analysis of Steel—Table I

Steel	C.	Mn.	Phos.	Sul.
A	.12	.38	.011	.037
B	.12	.34	.011	.042
C	.12	.31	.017	.047
D	.10	.28	.015	.049
E	.13	.25	.054	.037
F	.14	.25	.089	.054

range in gage. The sheets were cut into 3½-inch squares and the squares from each sheet thoroughly shuffled together and marked. Five squares were taken from each sheet for each experiment, and the sheets were prepared for annealing by packing in a small metal box and covered with clay and fine sand, special effort being made to exclude the air. The box was then placed in a small electric furnace and two annealings were made at each of the following temperatures: 1100, 1200, 1300 and 1400 degrees Fahr. The first run in each case consisted simply in bringing the furnace to the desired temperature, and then cooling it slowly. The second run in each case was conducted in the same manner except that when the desired temperature was reached it was maintained for a definite number of hours. The The furnace was so regulated that the rise in temperature approximated 100 degrees Fahr. per hour, and the cooling at about 50 degrees Fahr. per hour. This heating and cooling rate is very similar to the rate inside an annealing cover. As the tests annealed were so small it can be assumed that the temperature within the electric furnace would equal the actual temperature of the samples annealed.

After annealing, the squares were tested on an Erichsen machine and the results tabulated as in Table 1. A graphical representation of the same is shown in Fig. 6. Photomicropraghs of this test are shown in Figs. 7 to 14, the first three showing some rolling strains while the latter ones (annealed at 1300 degrees Fahr. or over) show grain growth. The Erichsen graph collaborates this and it seemed wise to carry on the experiment in the annealing room at 1200 to 1300 degrees Fahr. This temperature would give as good if not better results in stamping, and the sheets would open quite easily after annealing, since the lower temperature would be less harmful upon the furnace and

covers, and since there was a considerable saving of fuel, this new practice reduced annealing costs without deteriorating the product, in fact in many cases improving it.

Mill Study—Cannon Ball Type Furnace

In order to further carry out this test the temperature was taken on ten heats, couples being placed inside the boxes, and

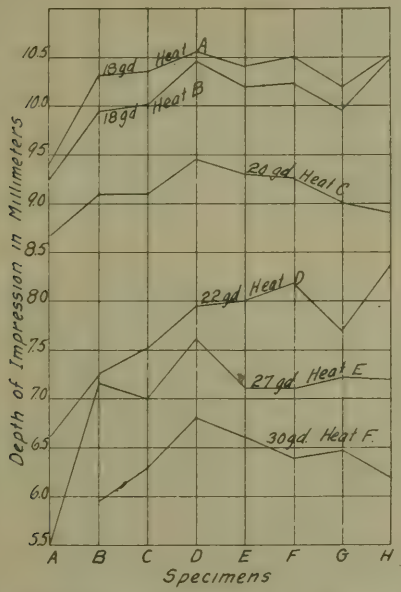

Fig. 6—Graphical Representation of Data of Table I. Specimen A, Heated to 1100 Degrees Fahr; Specimen B, Heated to 1100 Degrees Fahr., Held for 16 Hours; Specimen C, Heated to 1200 Degrees Fahr.; Specimen D, Heated to 1200 Degrees Fahr., held for 16 Hours; Specimen E, Heated to 1300 Degrees Fahr.; Specimen F, Heated to 1300 Degrees Fahr., held for 16 Hours; Specimen G, Heated to 1400 Degrees Fahr; Specimen H, Heated to 1400 Degrees Fahr., held for 16 Hours. All Specimens Cooled Slowly after Heating.

test sheets being taken out after annealing at a distance of one to two inches from the couple. The furnace curves on Test 7, Table II are shown in Fig. 15. The maximum and minimum temperature of the sheets on this particular heat is seen to be only 40 degrees Fahr. In the study on bench type furnaces, it will be seen that this variation runs up to 300 degrees Fahr which makes it quite impossible to correctly anneal the whole

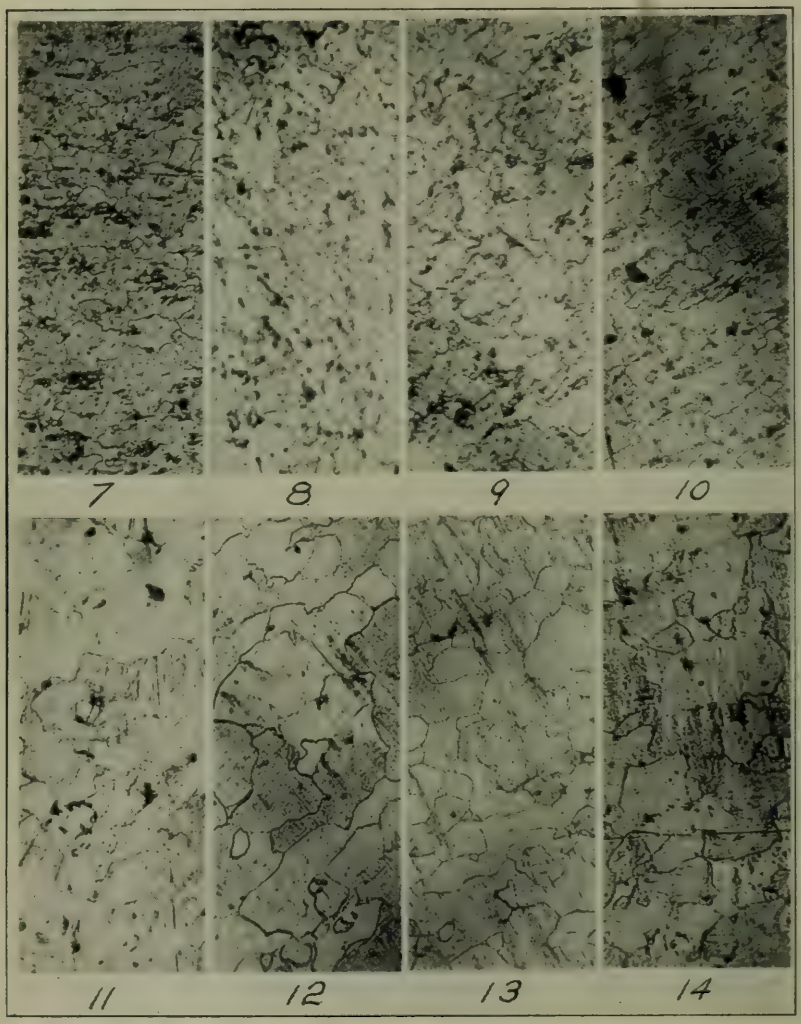

Fig. 7—Steel Heated Slowly to 1100 Degrees Fahr. Cooled slowly in Furnace. Fig. 8—Steel Heated Slowly to 1100 Degrees Fahr., Held at Temperature 18 Hours. Cooled Slowly in Furnace. Fig. 9—Steel Heated Slowly to 1200 Degrees Fahr. Cooled Slowly in Furnace. Fig. 10—Steel Heated Slowly to 1200 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Fig. 11—Steel Heated Slowly to 1300 Degrees Fahr. Cooled Slowly in Furnace. Fig. 12—Steel Heated Slowly to 1300 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Fig. 13—Steel Heated Slowly to 1400 Degrees Fahr. Cooled Slowly in Furnace. Fig. 14—Steel Heated Slowly to 1400 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Figs. 7-10 Show a Fairly Fine Grained Structure, Still Showing the Effect of Straining. Figs. 11-14 Show Well Formed but Large Grains. All Photomicrographs × 100.

Table II
Erichsen Test
Cannon Ball Type Furnace

Test No.	Position of Sheet in Box	Thickness in m.m.	Depth of impression in m.m. diagonally across sheet				Erichsen %	Box Average	Roof average during firing	Hours fired	Hours soaked	Total Time in Furnace	Max. Temp. at couple	Tests higher on Center or Edge
1.	A-Top	93	1000	1015	940	1000	1015	102.5	106.3	1834	13½	8	21½	1500	E
	C "	91	960		950		920	97.8						1450	
	E "	87	1000	1050	1090	1105	1070	111.7		Ave. Top—104.0%				1400	C
	B-Bot.	92	1100	1010	1080	1100	1100	111.6		Ave. Bot.—109.8%				1350	E
	D "	91	1046	1054	1080	1010	1010	108.0						1350	C
2.	A-Top	60	1025	980	963	1004	980	113.4	113.4	....	12	6	18	1440	E
3		91	1000	1020	1075	1055	1035	107.5	111.8	1934	10½	11	21½	1560	C
		90	1020		1156		1100	113.8							C
4.	A-Top	80	975	1100	1110	1140	1142	116.9	112.3	....	10½	11	21½	1470	
	C "	89	1055	1030	1060	1030	1015	108.5						1460	C
	B-Bot.	86	1110	1110	1147	1158	1080	118.0		Ave. Top—112.7%				1390	C
	D "	83	975	1060	1060	1025	1065	110.1		Ave. Bot—112.0%				1380	
	E "	79	990	1020	982	1025	1010	108.0						1360	E
5.	A-Top	80	1030	990	1010	975	974	106.7	109.3	1813	12	7	19	1480	
	C "	77	1040	1015	990	1050	995	110.0						1470	E
	E "	80	1065	1045	1053	1050	1070	113.1		Ave. Top—109.9%				1460	E
	B-Bot.	79	985	956	995	1020	1050	107.5		Ave. Bot—107.5%					
6.	A-Top	87	1043	1020	1080	1050	1050	110.1	113.7	1814	12½	2	14½	1380	C
	E-Top	81	1075	1065	930	1055	1070	113.8						1380	E
	B-Bot.	76	1020	1045	1030	1053	1080	113.3		Ave. Top—111.9%				1340	
	D "	80	1085	1115	1100	1140	1140	118.7		Ave. Bot—114.8%				1320	
	F "	80	1070	1065	1062	1000	1055	112.4						1310	
7.	A-Top	81	970	925	995	960	960	102.7	109.5	1945	10	11	21	1390	C
	C "	79	970	1050	1012	1052	1018	109.5						1380	C
	E "	75	1015	1000	1010	1000	1010	109.5		Ave. Top—107.2%				1380	
	B-Bot.	80	1055	1075	1015	1046	905	109.0		Ave. Bot—111.8%				1365	
	D "	78	1075	1000	1010	1031	1040	111.1						1360	E
	F "	77	1050	1085	1086	1046	1070	115.2						1350	C
8.	A-Top	80	975	965	965	950	970	103.3	107.5	1892	14	7½	21½	1475	E
	C "	77	1010	1028	1005	1025	1000	109.5						1460	
	E "	79	1042	1025	991	1005	1028	109.4		Ave. Top—107.4%				1450	E
	B-Bot.	80	923	975	985	982	995	104.0		Ave. Bot—107.6%				1395	
	D "	83	1000	1060	1000	1036	987	107.9						1390	
	F "	82	1060	1034	1060	1050	1000	110.7						1385	C
9.	A-Top	81	1040	1030	1066	1005	1120	112.3	114.2	1975	16	6	22	1425	C
	C "	62	1028	1035	1035	1005	1000	117.6						1410	C
	B-Bot.	65	1040	1030	1054	1040	980	115.6		Ave. Top—114.9%				1380	C
	D "	61	1030	1030	1041	1060	935	116.6		Ave. Bot—113.6%				1365	C
	E "	82	1020	1030	1057	1035	990	109.2						1350	C
10.	A-Top	78	985	980	970	985	1025	106.5	110.0	1850	8	8	16	1420	E
	C "	84	1140		1075		1060	115.5		Ave. Top—111.0%				1415	
	B-Bot.	86	1055	1070	962	1038	986	107.0		Ave. Bot—107.0%					E

AVERAGE FOR SHEETS—110.4%: FOR TOP SHEETS—109.7%: FOR BOTTOM SHEETS—111.0%.
12 edges ran higher than centers and 16 centers ran higher than edges.
Location of thermocouples shown in Fig. 17. Erichsen Standard for Stamping and Folding Sheets used.

charge. The material annealed in this test was 21 and 22-gage deep-stamping steel. It amounted to several hundred tons and was followed through the stamping operations. The breakage

was so low that it verified the Erichsen test readings. On Test I, Table II, the temperatures were taken for information only; thereafter the annealing was done as far as possible to conform with the laboratory practice. It will be noted in Fig. 15 that the temperature continues to rise within the box after the fire is cut off—because the steel absorbs quite a lot of heat from the furnace itself—and it took two or three heats before this rise could be estimated.

Test 3, Table II, produced quite a number of red sheets although the temperature was very high, showing that red sheets do not necessarily mean that the steel was under-annealed. The test taken as a whole showed over-annealing—at least as far as the temperature was concerned. The top sheets (which received more heat than the bottom ones) gave a slightly *lower* Erichsen value and the middle of all sheets as compared to the edges gave a *higher* value. This would seem like a very satisfactory check on the work. In Fig. 16 the furnace temperatures were plotted against the Erichsen percentage for each thermocouple, and clearly show a case of over-annealing. Table II is a record of all Erichsen tests, furnace temperatures, etc.

Mill Study—Bench and Charging Machine Type Furnace

As mentioned earlier in this paper the temperature variation within the box is much greater in this type of furnace. In Fig. 17 the inside temperature is plotted against the roof temperature and a wide variation (300 degrees Fahr.) was recorded. This furnace was a side-fired one, with two fire boxes and the charge in all four annealing boxes was of equal weight and size. While the rear-fired, (one fire box-type) has even more unequal heat distribution, the boxes are arranged in such position as to compensate for this. Erichsen tests on this study were very similar (at equal temperatures) to those in the previous study.

Hand Fired Versus Stoker Fired Furnaces

It was thought that a considerable saving in coal could be made by firing these furnaces by hand in place of using a mechanical stoker. Numerous tests were run on two similarly built furnaces, differing only in the method of firing. It was found

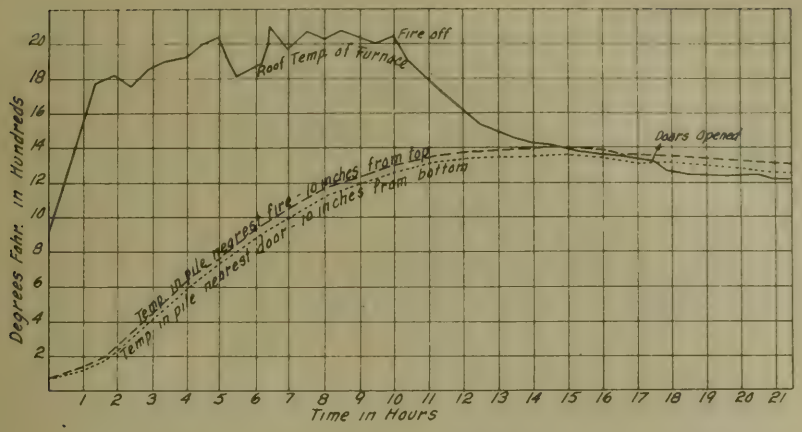
Degrees Fahr. in Hundreds
Time in Hours
Fire off
Roof Temp. of Furnace
Doors Opened
Temp. in pile nearest fire, 10 inches from top
Temp. in pile nearest door, 10 inches from bottom

Fig. 15—Cannon Ball Type—Single Stoker Furnace Curves Show Roof Temperature of Furnace, Temperature in Pile Nearest Fire and 10 Inches from Bottom, Temperature in Pile Nearest Fire and 10 Inches from Top. Charge Contained 15 Tons of Sheets and 12 Tons of Annealing Box. Test 1, Table II.

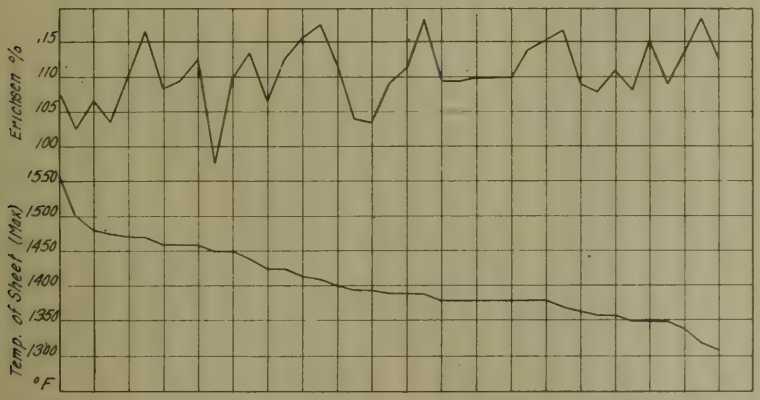

Fig. 16—Relation of Maxmium Annealing Temperature to Stamping Qualities of Sheet Steel as Shown by the Erichsen Test. Material was Deep Stamping Steel Annealed in a Cannon Ball Furnace. Data from Table II.

difficult to get equal weights of similar size sheets, covers and bottoms. The nearest approach to this is shown in Fig. 18. It was also deemed necessary in order to obtain a fair test, to fire at equal temperatures an equal length of time. The stoker-fired furnace burned 3542 pounds of coal to anneal 46,030 pounds of sheets, while the hand-fired one burned 4195 pounds on

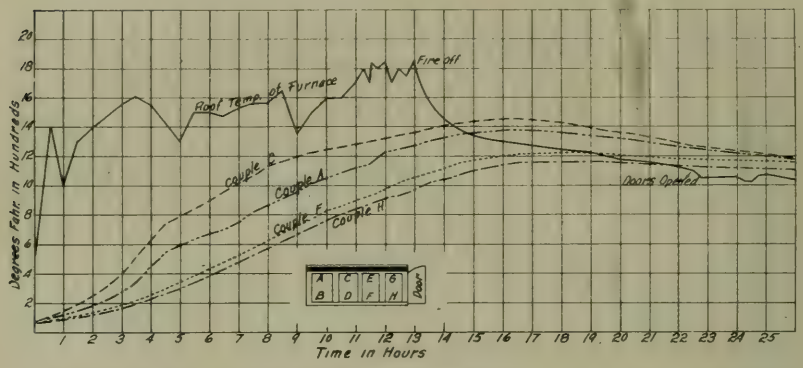

Fig. 17—Bench Type—Double Stoker—Side-Fired Furnace. Curves Show Roof Temperature of the Furnace, and the Temperature of the Boxes Within the Furnace. Position of Couples Shown in Sketch. Couples B, D, E and G Would Plot Between C and H Which are the Maximum and Minimum Temperatures of the Sheets. Data from Table II.

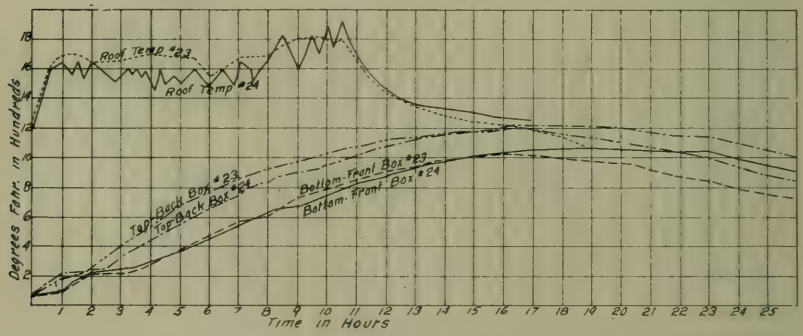

Fig. 18—Hand-Fired Versus Stoker-Fired Furnace, Showing the Results Obtained in a Test to Check the Relative Economy of Each Type of Furnace. An Average of All Tests Showed About an Equal Coal Consumption on Each Furnace with Labor Considerably Higher on the Hand-Fired Type.

52,755 pounds of metal. An average of all tests showed about an equal coal consumption with labor considerably higher on the hand-fired type, therefore, the use of stokers was continued.

General Practice

The majority of light gage, annealed sheets are pickled in sulphuric acid; the solution averaging about 8 per cent by volume. If this operation is done after annealing, it is necessary to put the sheets through a dryer. If it is done before, the annealing

furnace is in reality the drier. If the sheets are allowed to dry before they are covered and placed in the furnace, it is difficult to clean them. Therefore, it is advisable to charge them into a hot furnace at a temperature around 1000 degrees Fahr. Slow firing would undoubtedly reduce the difference in temperature between the top and bottom sheets but it is perhaps more im-

Table III

Temperature Differences During Firing

All Bench Type Furnaces except No. 2. Rear-Fired unless specified.

Test	Inside Temp. Degrees Fahr. Max.	Min.	Average Roof Temp. during Firing	Temp. During Time in Furnace	Firing Time	Soaking Time	Hours in Furnace	Diff. in Temp. Rise Per Hour Degrees Fahr.		Furnace No.
1.	1450	1050	1542	1459	13	3	16	85	400	24 Side Fired
2.	1400	1360	1846	1722	10	5	15	94	40	7-Cannon Ball Type
3.	1400	1290	1748	1628	9	6	15	94	110	14
4.	1340	1250	1565	1526	10	4	14	96	90	13
5.	1340	1280	1590	1552	11	3	14	96	60	14
6.	1300	1180	1567	1525	11 1/2	4 1/2	16	81	120	23-Side Fired
7.	1280	1170	1630	1563	9	4	13	100	110	13
8.	1275	1115	1485	1469	18	3	21	58	160	13
9.	1250	1210	1446	1431	16	2	18	70	40	14
10.	1250	1190	1478	1453	10	3	13	96	60	14
11.	1230	1180	1480	1413	10	3	13	95	50	14
12.	1220	1190	1525	1483	15	3	18	68	30	10
13.	1220	1180	1490	1458	14	2	14	87	40	13
14.	1200	1040	1706	1540	6	4	10	120	160	24-Side Fired
15.	1200	1020	1658	1536	11 1/2	4 1/2	16	75	180	23-Side Fired
16.	1200	1060	1596	1517	11 1/2	5 1/2	17	70	140	24-Side Fired
Average—	1285	1173	1585	1517	11.3	3 3/4	15 2	87	112	

portant to be able to clear them. Data on sixteen heats are given in Table III. The average roof temperature during the firing time was 1590 degrees Fahr. and was obtained in an average of 11½ hours. The soaking period (which does not figure in this average) was about 4 hours, after which the doors of the annealing furnace were opened and the boxes allowed to cool for three or four hours before removing. This delay seemed necessary because of the extreme heat which would work an unnecessary hardship on the men. It has since been found advisable to set a maximum roof temperature of 1800 degrees Fahr., and by bringing the temperature up as rapidly as possible, the annealing time has not been lengthened. After removing from the furnace, the boxes are set on the floor to cool, and the covers are not raised for 30 hours.

Such material as tin plates or any full finish cold rolled

(*Continued on Page* 216)

CONICAL ILLUMINATION IN METALLOGRAPHY

A New Method of Illuminating Opaque Objects Obliquely

By Harry S. George

Abstract

Conical illumination is a new method of lighting for microscopic examination and photomicrography of opaque objects. A more natural representation and clearer insight into structural relationships are its marked advantages. The present article describes and illustrates the method in its application to metallography at magnifications ranging from 100 *to* 4000 *diameters.*

ABILITY to distinguish and interpret metal structures is fundamentally affected by the method of illumination. For the present purpose, it is hardly necessary to do more than recall that the methods heretofore in use are of two distinctly different kinds. The distinguishing difference is that while in one system, light is admitted to the object through the objective, returning upon itself through the objective and being suitably deflected to the observer; in the other system, light is thrown on the object from some point outside the objective and then is reflected through the objective to the eye. The first system is known as vertical or axial illumination and the second, as oblique illumination. These two methods have reached a stage of almost complete development and have become so familiar to metallurgists through long use, that anything radical in the way of improvement or modification will be greeted with at least a degree of curiosity or even doubt.

Metallurgists become so familiar with metal structures that they perhaps do not realize that the mental picture seldom coincides with the physical image in the microscope. The process of examination has become second nature and the observer is not always aware that he is not actually seeing physically all that

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A paper to be presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, Harry S. George is associated with the Union Carbide and Research Laboratories, Inc., Long Island City, N. Y. Written discussion of this paper is invited.

he visualizes mentally. To take a simple illustration, a polishing scratch on a polished metallographic specimen appears under vertical illumination to be a black line on a bright surface. We interpret this to mean that a hard abrasive particle has plowed a furrow through a yielding metal even though the furrow is not seen. Again, a polygonal configuration of thin black lines on a bright surface is the outlined cross-section of grains of metal although few know the nature of these outlines, whether a grain boundary is a step down from one level to another, or a ditch etched out between grains, or a ridge. That which is seen through the microscope bears the same relationship to the structure that a mechanical drawing does to the object it represents. For example, when pearlite is examined under sufficiently high power, say 500 or 1000 diameters, the plates and globules of cementite ap-

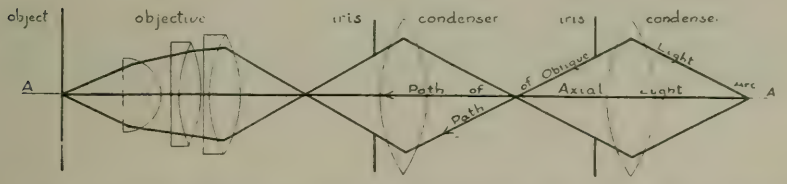

Fig. 1—Diagram of Path of Light in Metallographic Microscope, Using Vertical Illumination.

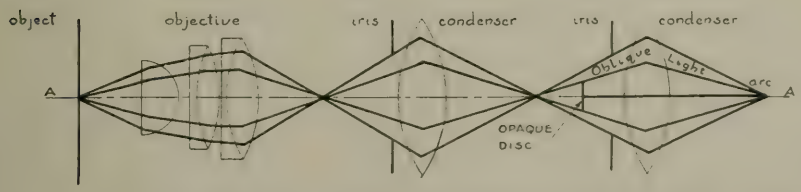

Fig. 2—Diagram of Path of Light in Metallographic Microscope Using Conical Illumination.

pear merely as outlined areas although their real condition is one of relief.

The reason why constituents are seen only in outline under vertical illumination is, of course, that they are illuminated by light parallel, or very nearly parallel, to the axis of the lens system, and as this light falls normally upon the surface of the ob-

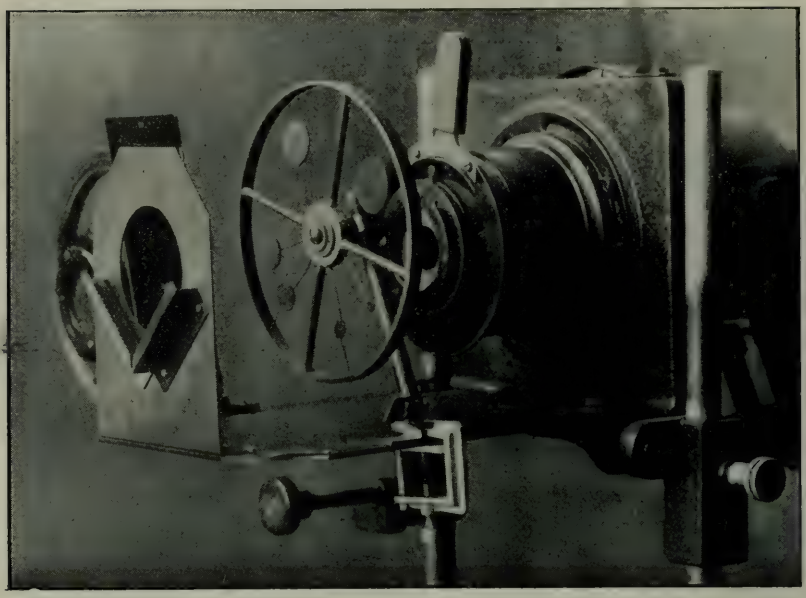

Fig. 3—Device for Obtaining Conical Illumination. The Discs are Mounted within a Wheel so that they may be Readily Adjusted in the Path of Light.

ject no shadows are cast and very little shading is manifest. This is an unnatural condition but has become so familiar as to seem natural. It results from the limitations imposed by the optical equipment, which necessitate, in the case of the higher magnifications, passing the illuminating beam of light through the lens system.

Even in the case of the lower powers where the working distance is sufficient to permit light to come to the object obliquely, the effect, while instructive in that it is open to interpretation, is nevertheless, subject to the criticism, owing to the extreme obliquity of the light, of being an unnatural representation. The contrast between the appearances of a structure viewed by the above mentioned systems of illumination is very striking and is too well known to need discussion.

It would be desirable, then, to view microscopic objects in a more natural way: to see them in relief, as one sees a man's facial characteristics. Furthermore, as the trend of practice seems

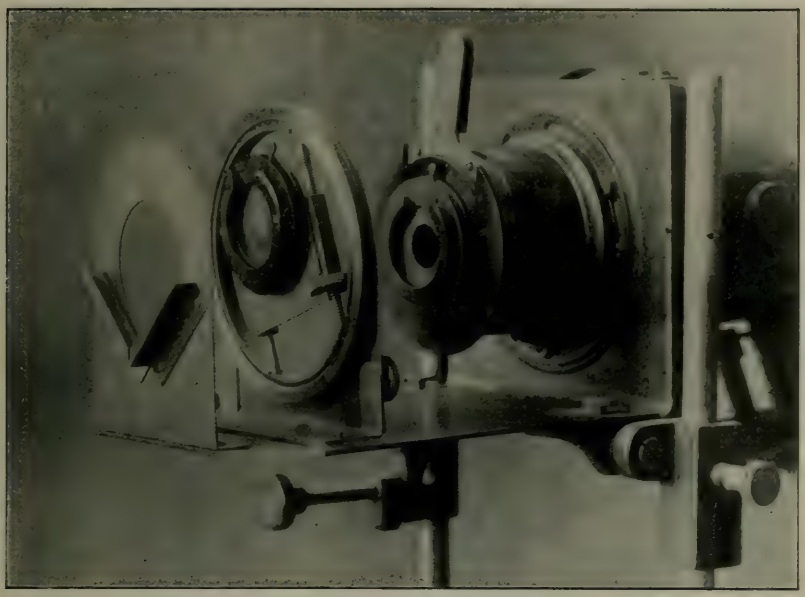

Fig. 4—Device for Obtaining Conical Illumination Using an Auxiliary Iris Diaphragm Mounted within a Wheel Whose Center is at the Optic Axis.

to require examination at higher magnifications, any method imparting a natural appearance should be adapted to high power lenses.

Conical Illumination Described

The method described in this paper is applicable to all objectives for it is based on the fact that the objective itself is transmitting oblique as well as axial light to and from the object. Reference to Fig. 1 will make this clear. The arrangement shown is purely diagrammatic, the usual glass reflecting disc, stellite mirror and eyepiece being omitted for simplicity. Also, of course, in actual practice, the light source is not a point nor is it situated at the focal distance from the condenser. The design of the figure is merely to show clearly the fact that so-called axial illumination is really composed of true axial light and, also, of oblique light.

Light traveling approximately parallel to axis A.A of the lens system (axial light) falls normally upon the object and masks

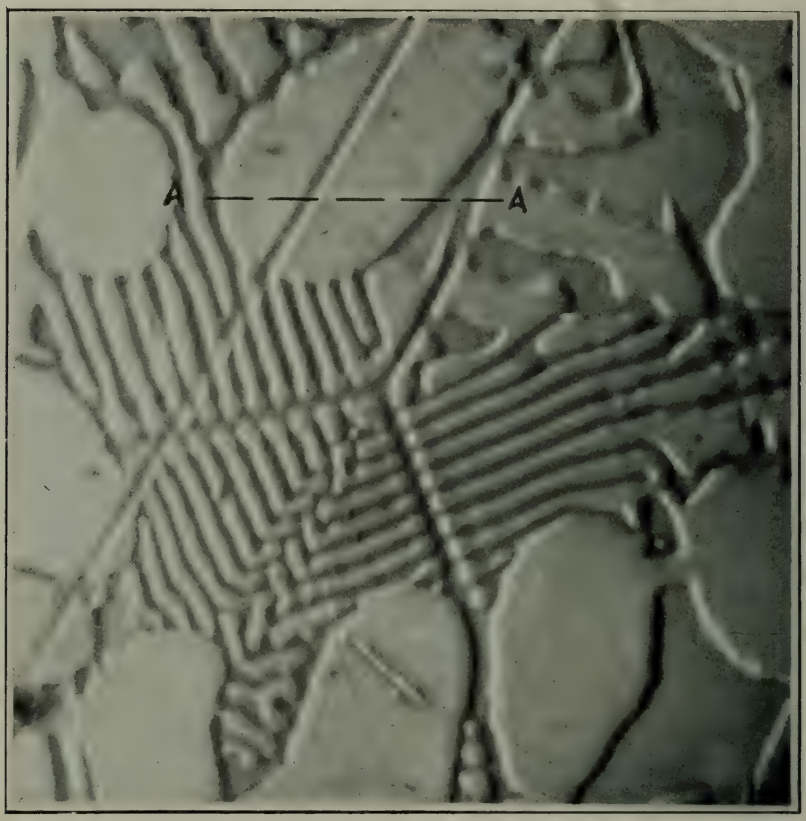

Fig. 5—Photomicrograph of Etched, Complex Alloy Under Conical Illumination. This Photomicrograph Shows the Same Field as Fig. 5-R (Opposite Page), but, in Photographing, the Direction for Illumination for Fig. 5 was from Left to Right, While for Fig. 5-R it was from Right to Left. (x 4000, 1.9 mm. objective, 10.0 x eyepiece.)

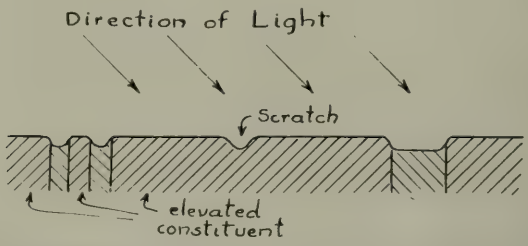

Fig. 7—Sketch Showing the Profile of Scratch (at AA, Fig. 5) Illustrating Method of Determining Direction of Light Used in Photographing.

Fig. 5-R—Photomicrograph of same Field as Fig. 5. If Fig. 5 and Fig. 5-R are Illuminated by a Strong Light from the Left Fig. 5-R Usually Presents an Illusion, Making the Broad Light Areas Appear Depressed, Whereas in Reality They are Elevated as Usually Apparent in Fig. 5. (x 4000, 1.9 mm. objective, 10.0 x eyepiece.) Fig. 6 on Next Page Shows the Same Field with Ordinary Vertical Illumination.

any relief effect produced by the oblique light. To obtain relief, it is only necessary to stop out axial light. One way of doing this is to place an opaque disc in the illuminating beam perpendicular to the axis AA. (See Fig. 2.) An image of the disc is formed near the back lens of the objective, thus producing a hollow cone of light in the objective, having its apex on the object.

Since making this simple discovery, it has been pointed out to the writer that the method is essentially similar to oblique illumination by means of a substage condenser and stop in ordinary microscopic work with transmitted light. With reflected

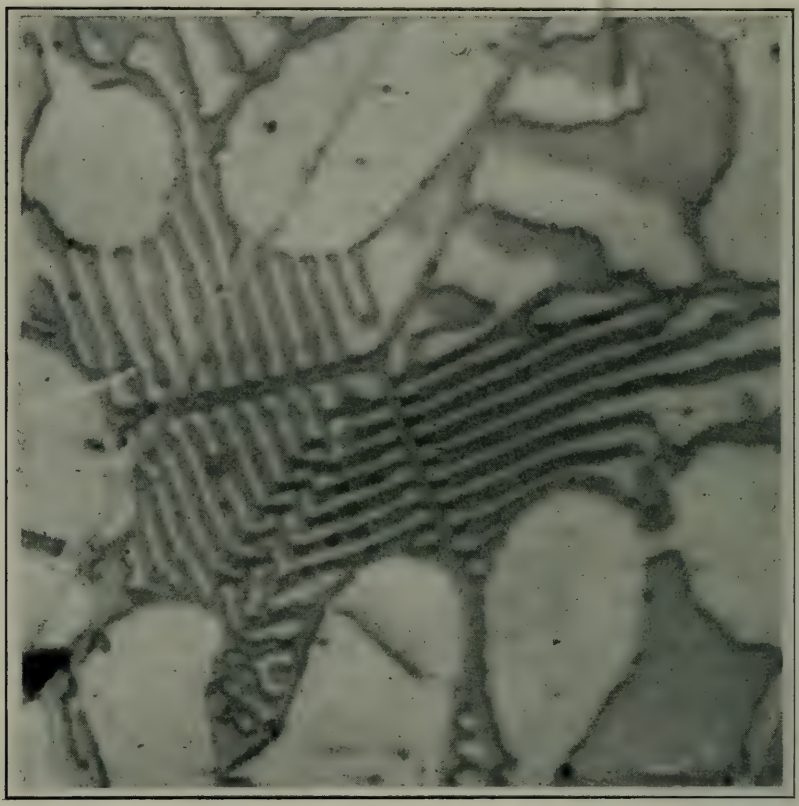

Fig. 6—Photomicrograph of Same Area as in Figs. 5 and 5R Taken with Ordinary Vertical Illumination. (x 4000, 1.9 mm. objective, 10.0 x eyepiece.)

light and vertical illumination, the objective takes the place of the substage condenser and instead of placing a stop at the back lens of the objective, this method virtually places one there by the expedient of locating the image of one at that point.

The disc is preferably placed slightly eccentric so that light will fall upon the object from one direction. The particular direction of illumination, as well as the size of the disc, is best determined by trial for each individual subject and purpose.

While in some cases a definite, fixed size and position of stop is adequate, yet in most instances it is desirable to be able to rapidly change the size of stop and to rotate the direction of light.

For this purpose, the writer has had constructed the two devices illustrated in Fig. 3 and 4.

The contrivance shown in Fig. 3 is simply an assortment of stops of different sizes mounted on the spokes of a wheel. As the wheel is rotated, any stop can be swung into position. The arm on which the wheel is mounted is pivoted at its base so that the entire appliance can be swung out of the way. Any stop may be rotated about the optic axis by a compound rotary and pivotal motion of the wheel. The shadow of the stop on the filter affords a convenient means of noting its position.

The device illustrated in Fig. 4 serves the same purpose in a different way. It consists of an auxiliary iris diaphragm mounted within a wheel whose center is at the optic axis. The knurled adjusting nut controls the degree of eccentricity of the auxiliary iris. With the microscope nicely adjusted, the latter method is more conveniently operated than the one first described. Moreover, it is the more rugged in construction but has the disadvantages of requiring more accurate adjustment of the microscope and of cutting down the amount of light.

Terminology

In the following, the term conical oblique illumination or simply conical illumination will be used to designate the method just described to distinguish it from oblique illumination as ordinarily applied. The terms vertical, normal and axial illumination refer to so-called vertical, that is, mixed axial and oblique illumination, commonly obtained when the object is illuminated through the objective.

Microscopic Appearances

Oblique light as ordinarily applied is so nearly parallel to the surface of the object that it is not reflected from a perfectly plane surface through the objective to the eye because the angle of reflection equals the angle of incidence. Consequently, plane surfaces appear dark by ordinary oblique illumination and bright by ordinary vertical illumination. Rough surfaces, depressions, or elevations for the same reason, appear either light or dark depending on whether they are viewed by ordinary oblique or by ordinary

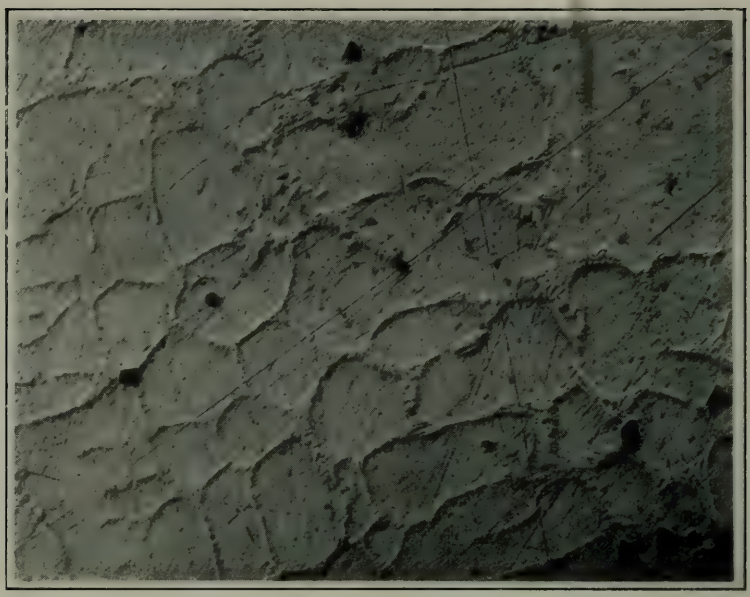

Fig. 8—Photomicrograph Under Conical Illumination of Etched Chrome-Iron Alloy, Showing Hard Carbide Standing in Relief in Eutectic Which Forms the Grain Boundaries. (x 250, 16 mm. objective, 6.4 x eyepiece.) Compare with Fig. 9.

vertical illumination. In other words, the view obtained by ordinary oblique light is the negative to the positive appearance obtained from ordinary vertical illumination.

Conical oblique light, on the other hand, does not give this negative appearance. The rays of light in this case are more nearly parallel to the optic axis and, therefore, are reflected back through the objective from plane surfaces, making them appear bright, as with so-called vertical illumination, and imparting a natural relief effect to the appearance.

Conical Illumination Adapted to High Power

Resolution, which is the optical quality of differentiating or distinguishing as such two lines which lie side by side, is directly proportional to the numerical aperture of the objective. In general, the greater the aperture, the more resolution attainable. Also, the greater the aperture, the more oblique are the outer rays in the light cone, between the objective and object. It is also evi-

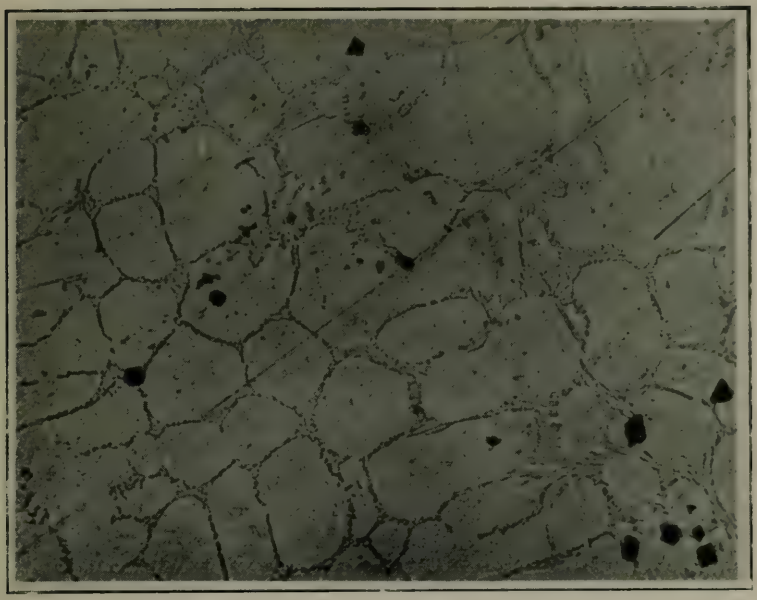

Fig. 9—Photomicrograph of the same Field as Fig. 8, Also Unetched, but taken with Vertical Illumination. Note absence of Relief in Fig. 9. (x 250, 16 mm. objective, 6.4 x eyepiece.)

Fig. 10—Photomicrograph of Unetched Chrome-Iron Alloy of High Carbon Content Under Conical Illumination (x 500, 4 mm. objective, 6.4 x eyepiece).

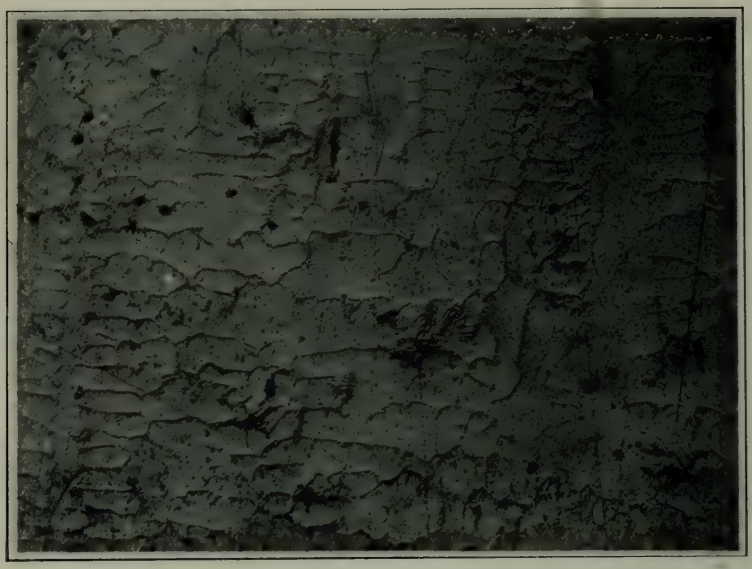

Fig. 11—Photomicrograph of Chrome-Iron Alloy Under Conical Illumination, Specimen Unetched, Structure Being Revealed by the Method of Lighting (x 100, 16 mm. objective, 6.4 x eyepiece). Compare Fig. 12.

dent that immersion oil will increase the obliquity of the extreme rays because its index of refraction is greater than that of air. As the method of conical illumination depends for its effects on the obliquity of the light passing through the objective, it follows from the above optical considerations that it is particularly adapted to high power work.

Illustrations and Apparatus

The accompanying micrographs will illustrate the method in its application to low and high power objectives. They were taken with a Bausch & Lomb inverted metallurgical microscope and camera mounted on a horizontal bed. A Wratten B filter was used in conjunction with a direct current arc for illumination. Achromatic objectives and Huygenian eyepieces were used in all cases. The photographic plates were standard orthonon.

An Optical Illusion

With few exceptions the micrographs shown here, which were taken by oblique conical illumination are orientated the same with

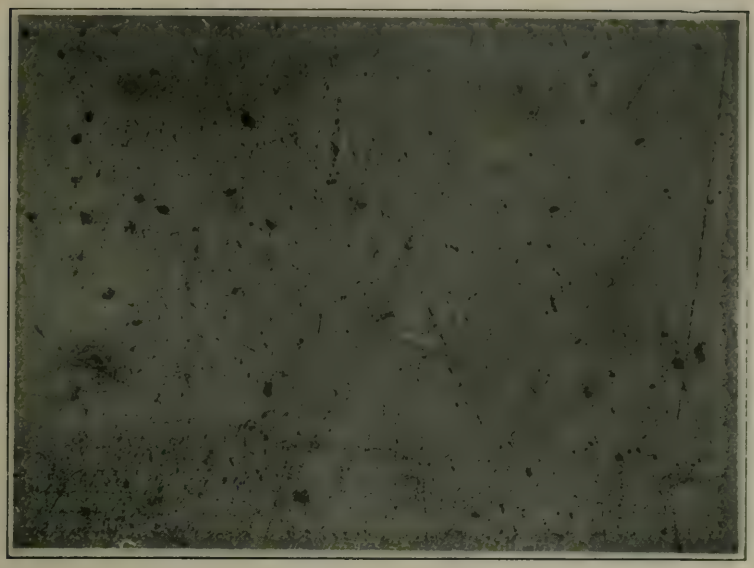

Fig. 12—Photomicrograph of the Same Field Shown in Fig. 11, but Under Vertical Illumination. The Structure is Hardly Visible Owing to the Absence of Relief. (×100, 16.0 m.m. objective, 6.4 eyepiece.)

respect to the direction of light used in photographing which is, with respect to these pages, downward from left to right, at an angle of 45 degrees. The left side of elevations and the right side of depressions will then appear bright. The sense of sight is very easily deceived, however, and unless the direction of light used in photographing is known, it is impossible to tell, in the case of unknown structures, whether the appearance is real or an illusion. It will aid in avoiding the illusion if the light used in examining the micrographs be a strong one and have the same direction as that used in photographing.

One of the exceptions in orientation mentioned above is Fig. 5R which, when compared with Fig. 5 under a strong light from the upper left illustrates the illusion referred to. Under this condition of lighting most observers see Fig. 5R as the inverse of Fig. 5. The reason for this is that while the fields are orientated the same the direction of light was reversed in Fig. 5R. What are elevations in one seem to be depressions in the other. Turning the pictures upside down or allowing the light to come from lower right usually inverts the appearance of both pictures. When

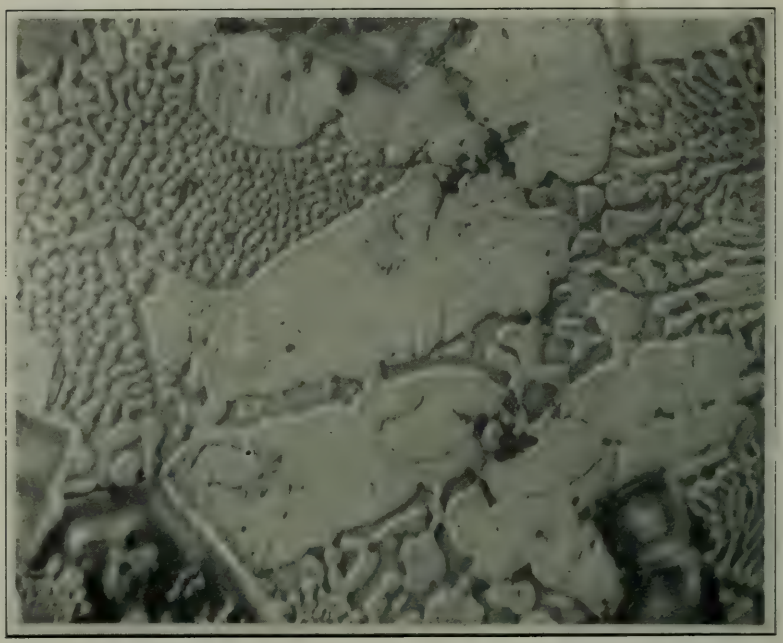

Fig. 13—Photomicrograph of Etched Complex Alloy Under Conical Illumination (x 2000, 1.9 mm. objective, 6.4 x eyepiece).

one is familiar with a particular structure the illusion rarely occurs irrespective of the direction of light used in photographing relative to that illuminating the picture. The illusion may also manfiest itself while an object is being examined through the microscope, but only rarely with known structures or when a known detail such as a polishing scratch is visible in the field.

The point to be emphasized in connection with conical illumination is that in interpretation of structure, it is dangerous when examining an unknown structure to rely on appearances. For correct interpretation, the direction of illumination must be known. The facts of relief must then be deduced. If the appearance coincides with the deduction, it is real. If it does not, it is an illusion. When this process has been applied to a view which persists in being an illusion, it will suddenly invert and present the true appearance.

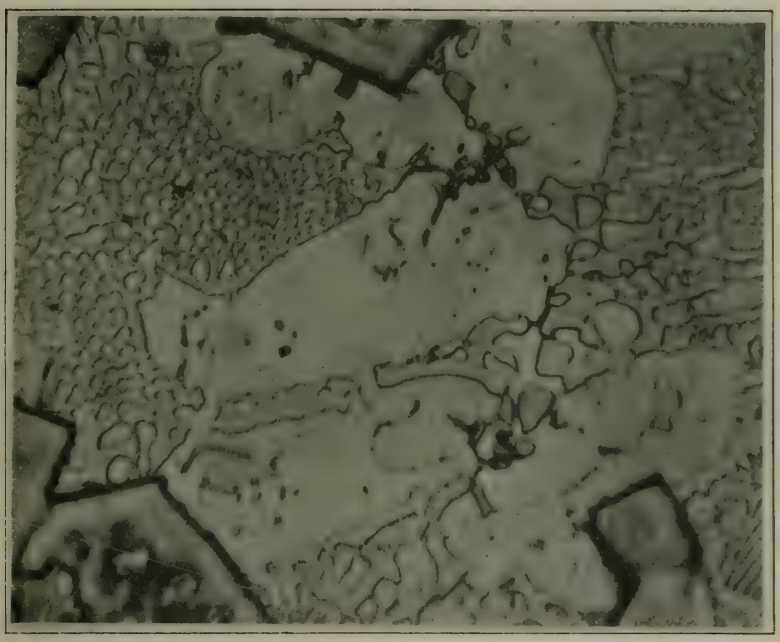

Fig. 14—Photomicrograph of the Same Field as Fig. 13 Under Vertical Illumination. (x 2000. 1.9 m.m. objective, 6.4 x eyepiece.)

Value of Polishing Scratches

Because of the foregoing when examining an unknown structure, if this illusion proves confusing, it is advisable to analyze the structure with reference to a known surface detail such as a polishing scratch. If a scratch is large enough or under sufficient magnification it serves as a criterion to determine whether the illusion is present. Reference to Fig. 5 and 7 will make clear the use of a scratch in determining the direction of the light. Fig. 7 is a profile across the scratch at AA. From Fig. 5, it will be seen that the left side of the scratch is darker than the right, hence the light is coming from left to right as shown by the arrows in Fig. 7.

Incidentally, polishing scratches will be found to be of material assistance in determining structural characteristics, as for example, relative hardness and malleability of microconstituents. This application is brought out in Fig. 5, 8 and 10.

Fig. 15—Photomicrograph Under Conical Illumination of the same Field as Fig. 5, but at Lower Magnification. Angular Areas are Depressions, Rounded Patches are Raised. The Inverse Appearance is an Illusion. The Diagonal Line is a Polishing Scratch (depression). (x 2000. 1.9 mm. objective, 10 x eyepiece.)

Practical Application

The specimen shown in Fig. 10, is an alloy of 32.0 per cent chromium, 65.0 per cent iron and 3.0 per cent carbon, well known for its resistance to abrasion and its ability to withstand oxidation at elevated temperatures. The reason for the first quality, as clearly shown in Fig. 10, is the presence of a very resistant constituent held in a softer matrix. The hard constituent polishes in relief (the micrograph is of the unetched specimen) and even resists the abrasive particle which made the deep interrupted diagonal scratch across the field. Under vertical illumination, merely a faint tracery is visible with no relief and the specimen must be etched to reveal the structure. After etching, the scratch is no longer visible. Fig. 11 ($\times$100 unetched) illustrates the same combination of hard and soft constituents but in different proportions. Fig. 12 is of the same field as Fig. 11, but was taken with ordinary, so-called vertical illumination.

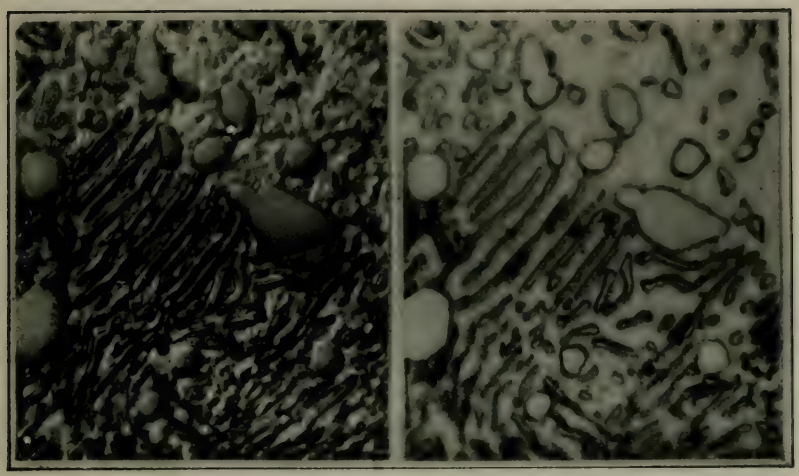

Fig. 16—Photomicrographs of 1.5 per cent Carbon Steel Showing Both Spheroidized and Lamellar Pearlite, under Oblique (conical) Illumination. Etched with 5 per cent Picric Acid in Alcohol. (x 2000, 1.9 mm. objective, 10 x eyepiece.)

Mode of Discovery

Another interesting feature attending the use of oblique lighting is to be noted in Fig. 11, namely, the appearance in the same micrograph of structural details and nonmetallic inclusions. The usual method of developing structural details by etching, may mask or obliterate nonmetallic inclusions. In fact, it was in an effort to find some means of bringing out structure without obliterating inclusions that the method described was found. This application is brought out perhaps even more clearly in Figs. 8 and 9 ($\times$250 unetched) which are of the same material but at a higher magnification.

Method Illustrated

Fig. 10 ($\times$500, unetched) has already been referred to. In this case, etching would undoubtedly develop the finer structural details to a greater extent. It will be noted in this and other examples that the magnification must be properly chosen to fit individual requirements.

Fig. 13 and 14 ($\times$2000, etched) are of a different material at higher magnification, as is also Fig. 15 ($\times$2000, etched).

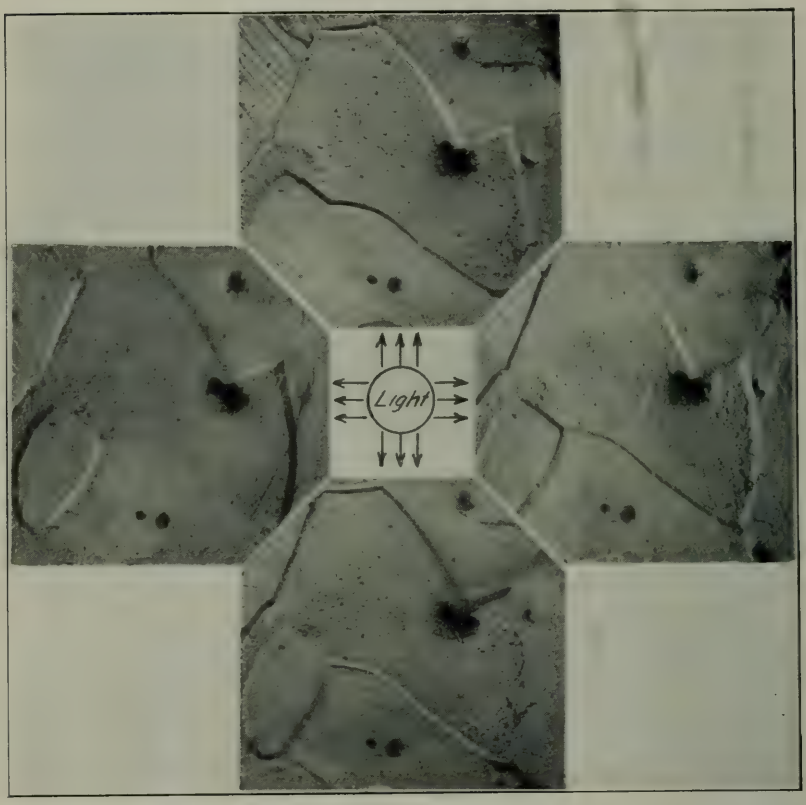

Fig. 18—Photomicrographs showing Grain Boundaries in Ferrite. This Figure Shows the Same Field under Conical Illumination from Four Directions as Indicated by Arrows. (x 500, 4 mm. objective, 6.4 x eyepiece).

Incidentally, the angular material in Fig. 15 has been proven, by focussing measurements, to be actually deeply recessed by etching. This corroborates the evidence furnished by the scratch which runs diagonally across the field in Fig. 15, i.e., the field was lighted from the left and, therefore, the light colored areas, whose west slopes are lighted and whose east slopes are shaded, are plateaus. Likewise the angular areas, whose west sides are shaded and whose east sides are lighted, are hollows, etched out.

Fig. 5, 5R and 6 ($\times$4000, etched) are of the same field as Fig. 15 but at twice the magnification. No advantage is derived from the higher magnification. It is apparent, however,

that magnification is no obstacle to this method. Fig. 5 and 5R have already been discussed, their purpose being to illustrate the optical illusion referred to.

Fig. 16 and 17 (×2000, etched) illustrate the familiar structure of pearlite but the combination of lamellar and spheroidal pearlite in the same field is rather unusual and offers a good subject to illustrate the advantage of conical over vertical illumination, as regards realism and attractiveness. The appearance of the iron carbide, cementite, standing in relief (Fig. 16) suggests this method as a means of distinguishing it from ferrite in grain boundaries instead of the usual treatment with sodium picrate.

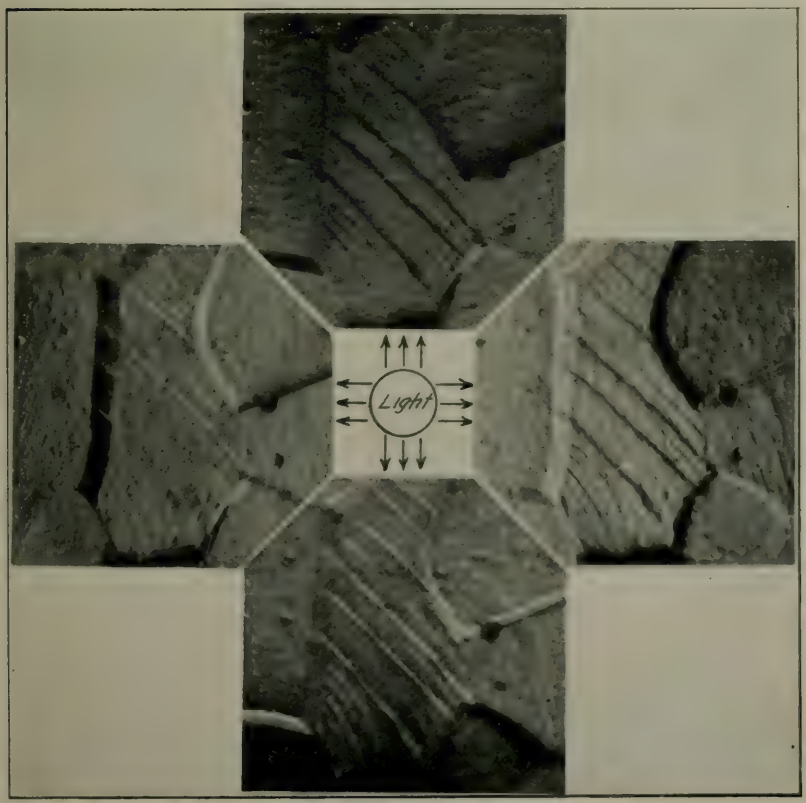

Fig. 19—Photomicrographs Showing Slip Lines and Grain Boundaries in Ferrite. This Figure Shows the Same Field Under Conical Illumination from Four Directions as Indicated by Arrows. (x 1000, 1.9 mm. objective, 6.4 x eyepiece.)

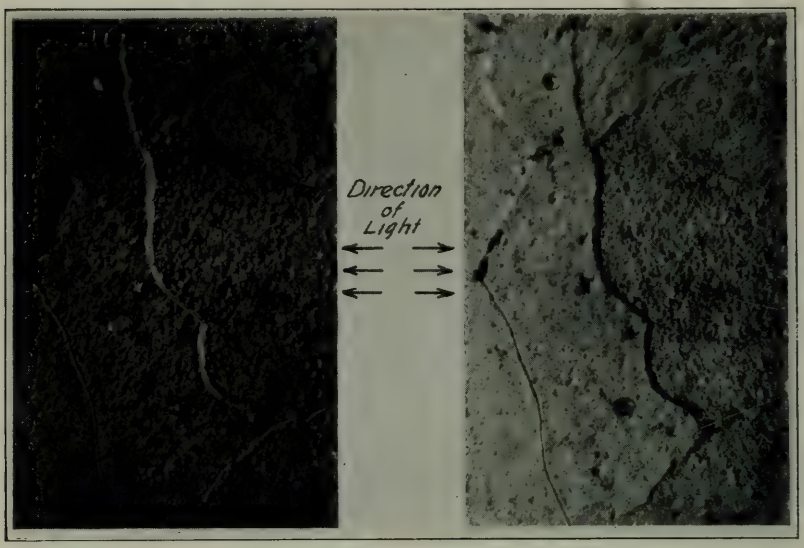

Fig. 20—Photomicrographs of Ferrite Grains under Conical Illumination from Opposite Directions as Indicated by the Arrows. Note "Step" and "Ditch" Types of Grain Boundaries. (x 500, etched, 4.0 mm. objective, 6.4 x eyepiece.)

Grain Boundaries Under Conical Illumination

In the introductory remarks of this paper the nature of grain boundaries was referred to. In the case of a pure metal, or of a solid solution, it has been inferred by some from focussing measurements that the surfaces of individual grains etch to varying depths owing to the differential existing between the rates of attack along different crystallographic axes. From this it is commonly conceded that black lines representing grain boundaries are really steps from one grain level to another. If this needs corroboration, it receives it from examination of grain boundaries under conical illumination. In Fig. 18 is shown the appearance of grains of ferrite etched with picric acid in alcohol, strained by compression, and magnified $\times 500$ under conical illumination. A similar series, taken with oil immersion objective ($\times 1000$) of a different field, is shown in Fig. 19.

The difference between the photomicrographs in Fig. 18 and 19 illustrates an interesting application of conical illumination similar in effect to that produced under ordinary oblique light

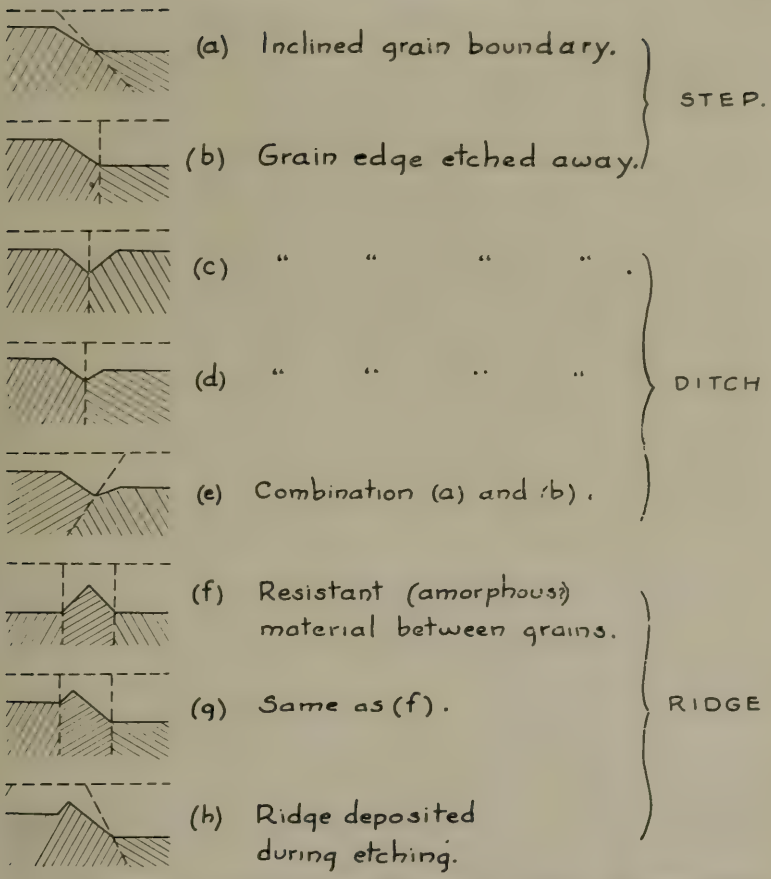

Fig. 21—Diagrams of Types of Grain Boundaries in Ferrite. Horizontal Broken Lines Represent Original Polished Surfaces before Etching. Inclined Broken Lines Represent Grain Boundaries Below the Surfaces. Solid Lines Represent the Etched Surfaces. Hatch Lines Indicate Difference in Orientation between Adjacent Grains.

by rotating the specimen. In the present case, the direction of illumination was changed in 90 degree steps. Thus, in the left hand photomicrograph the direction of the light for photographing was, with respect to these pages, horizontally from right to left; that for the upper photomicrograph was vertically upward; for the right hand photomicrograph horizontally from left to right, for the lower photomicrograph vertically downward. Knowing the direction of illumination, it is easy to tell by inspection, the relative elevations of the grains.

In addition to corroborating the step theory of grain boun-

daries, several other features are revealed by these illustrations. Referring to Fig. 18, (upper and lower photomicrographs), the short horizontal grain boundary in the top center is evidently a ridge, for in the upper photomicrograph, its lower slope is lighted and its upper is dark, while in the lower photomicrograph, the reverse is true. Furthermore, the curving grain boundary in the center of the figure will be seen, at its horizontal sector, to be a combination of ridge and step. A third type of boundary is seen in Fig. 19 (right hand and left hand photomicrographs). The boundary between the central and lower left hand grains is evidently a ditch, both grains being at the same level. This type is more clearly shown in Fig. 20, showing Norway iron magnified 500 diameters. In this pair of photomicrographs, the particular boundary which illustrates the ditch type is the vertical one at the lower left of the field. In the left hand photomicrograph, lighted from the right, the left side of the boundary is bright, while in the right hand photomicrograph, lighted from the left, the right side is bright. By the same process, the parallel boundary in the center is seen to be a step, that is, the left central grain is higher than the right central grain.

An interesting etching phenomenon is to be seen in these two micrographs for which no explanation seems satisfactory. It will be noted that the left central grain is pitted while its neighbor, at a lower elevation, is pebbled. The writer has observed this condition to be consistent, that all grains which have been etched below their neighbors have pebbled surfaces while the higher ones are pitted.

Without digressing too far it may be worth while to mention some observations which have been made with the aid of conical illumination on the nature of grain boundaries. These observations by no means clear up the questions involved in this connection. Indeed they probably will complicate the present hypotheses. For example, does a ridge at a grain boundary indicate a more resistant material or does it indicate deposition during etching? And why are ridges not evident at all boundaries (of the same material)?

Fig. 21 depicts various types of grain boundaries observed under conical illumination in very mild steel. An attempt is made by dotted lines to reconstruct the grains, as they were before etch-

ing, and to indicate the continuation of boundaries below the surface. The unshaded portions represent metal removed by etching. It is thought that these sketches will be suggestive in themselves of various possibilities in the way of explanation.

Practical advantages of the method suggest themselves continually, not the least of which the writer has found to be the sense of pleasure and lack of fatigue attendant upon its use. Without doubt, this is the consequence of viewing objects in the microscopic field in their natural relationships.

In conclusion, the writer takes this opportunity to acknowledge his indebtedness to Dr. Ancel St. John for much helpful discussion and particularly for his suggestion of the term "conical illumination"; likewise to Dr. Thomas W. B. Welsh for helpful criticism in connection with the optical analysis of the subject; also to W. P. Melville for many suggestions and for the prints which accompany this article.

ABNORMAL GRAIN GROWTH IN COLD ROLLED LOW CARBON STEEL

By Victor E. Hillman and Frederick L. Coonan

Abstract

This paper reviews the research work conducted in determining the factors and conditions causing abnormal grain growth in steel, resulting from annealing critically cold-rolled low-carbon steel. The four principal factors are carbon content, critical strain, temperature and time. The results show that a draft of 7.5 to 15 per cent should be avoided in cold-rolled steel used for vital parts.

Introduction

THE object of this research was to inquire into the underlying principles governing crystallization. The term "crystallization" as hereinafter used refers to that grain growth which is disclosed in low carbon steel when the metal is subjected to a certain degree of strain and temperature. In metallurgical parlance, this phenomenon is known as "Stead's brittleness."

In 1898, Stead discovered the presence of enormously large grains in soft steel. He found that if low carbon steel is subjected to a definite strain, and subsequently annealed at a temperature below the Arl point, the ferrite grains undergo a marked crystalline transformation. That is to say, the adjoining ferrite grains merge to form a large grain. This coarse structure is decidely detrimental to steel, causing the metal to suffer a noticeable decrease in its elastic limit, elongation, reduction of area, and fatigue resisting qualities.

Factors Affecting Grain Growth

At the outset, it may be well to state that grain growth is a function of four factors; namely, carbon content, critical

A paper to be presented before the annual convention of the Society to be held in Pittsburgh, October 8-12, 1923. Of the authors, V. E. Hillman is metallurgist and F. L. Coonan is assistant metallurgist with the Crompton & Knowles Loom Works, Worcester, Mass. Written discussion of this paper is invited.

strain, temperature, and time. Authors disagree to a slight extent as to the maximum percentage of carbon which will forestall crystallization. Some metallurgists claim that it cannot be developed in steel containing more than 0.15 per cent carbon, while others contend that the phenomenon continues to manifest itself until the carbon is in excess of 0.18 per cent. However, such subtle distinctions are merely of passing interest.

The development of critical strain is dependent upon the expenditure of energy. It is immaterial what agency is employed. In fact, any force that causes the ferrite grains to assume the same orientation, supplies the first requisite for grain growth. Therefore, when low carbon steel is cold rolled, sufficient pressure may be exerted to produce critical strain. On subsequent annealing, crystallization will result providing the operation is conducted at a specified temperature slightly below the Arl point. Hence, the aim and purpose of this investigation was designed to serve a triple purpose; first, to ascertain the degree of draft in cold rolling which will produce critical strain, second, to determine the temperature range in which grain growth becomes apparent, third, to decide what influence various percentages of carbon exert on the mechanism of grain development.

This research required three grades of basic open-hearth steel, namely, 0.08 per cent carbon; 0.10 per cent carbon; and 0.13 per cent carbon, with the other elements normal. Previous to the application of cold work, the steel was annealed for the purpose of relieving such strains as might have been induced as a result of hot rolling.

Procedure—0.08 Per Cent Carbon Steel

A strip of stock—4 feet long by 6 inches wide was given a pass through a mill of the ordinary cold rolling type. The metal suffered a reduction in thickness of 2 per cent. A test specimen 7 inches long by 6 inches wide was cut off for experimentation. The remaining product was again reduced in thickness 3.5 per cent, whereupon another sample was procured. This scheme of procedure was continued until samples repre-

senting the following reductions in thickness were obtained; namely:

Reduction per cent	Reduction per cent	Reduction per cent
2.0	15.0	61.0
3.5	19.0	66.0
4.0	21.0	68.0
5.0	29.0	72.0
7.5	35.0	75.0
8.0	40.0	77.0
10.0	48.0	80.0
14.0	58.0	

This method of procedure produced 23 samples representative of various degrees of cold work. It was reasonable to assume, therefore, that some of the specimens had been critically strained. The 23 specimens were annealed at 1250 degrees Fahr., for a period of 8 hours. The reason for selecting this temperature will be hereinafter noted. Micro-examination revealed full and complete grain growth in the specimen which received a 7.5 per cent reduction in thickness. In the section reduced 10 per cent a few large crystals and a semi-growth were detected. The character of the latter structure resembled a transition stage. Similar features were observed in the specimens which had received a draft of 14 and 15 per cent.

Observations point to the conclusion that as the degree of draft approaches 15 per cent there appear (at 7.5 per cent reduction) very large grains, second, (at 10 and 14 per cent reduction) semi-growth and finally, as the strain exceeds the "critical" (15 per cent reduction) the grains revert to the characteristic structure of an anneal below the Arl. Therefore, the critical strain occurred within a reduction range of 7.5 to 15 per cent inclusive. It is to be noted, however, that the maximum crystalline growth occurred at 7.5 per cent reduction.

The specimens which were reduced,

Per Cent	Per Cent	Per Cent
19	48	
21	58	75
29	61	77
35	66	80
40	72	

developed no increase in grain size. Hence, these specimens were strained beyond the critical point. It might be said that they were over-strained. By the same token, the specimens which were given a draft reduction of 2, 3.5, 4 and 5 per cent may be designated as understrained, for the reason that crystalline growth did not develop during the thermal treatment.

Temperature Range—Productive of Crystalline Growth

Abnormal grain growth in critically strained steel is confined to definite temperature limits below the Arl point. Moreover, carbon plays an important role in regulating this growth-producing temperature range. Observations pointed to the fact that as the carbon content of the steel approached 0.15 per cent the temperature range in which coarse crystallization occurred was confined to narrower limits.

For the purpose of determining the extent of this variance, three grades (0.08, 0.10 and 0.13 per cent carbon) of critically strained steel were annealed at the following temperatures for 8 hours;

Degrees Fahr.	Degrees Fahr.
1150	1400
1250	1450
1300	1500
1350	

In the 0.08 per cent carbon steel, a slight degree of coarse crystallization was in evidence in the specimens annealed at 1150 degrees Fahr. Complete growth occurred at 1250, 1300, 1350, 1400 and 1450 degrees Fahr., whereas, at 1500 degrees Fahr., no growth was discernible. Therefore, the growth-producing range is between 1150 and 1450 degrees Fahr. for an 0.08 per cent carbon steel.

In the 0.10 per cent carbon steel, grain growth occurred at 1250, 1300, 1350, 1400 and 1450 degrees Fahr., whereas in the 0.13 per cent carbon steel, coarse crystallization took place at 1300, 1350, 1400 and 1450 degrees Fahr. Hence, the growth-producing temperature range for 0.10 per cent carbon steel lies between 1250 and 1450 degrees Fahr., while on the other hand, the development range for a 0.13 per cent carbon steel is between 1300 and 1450 degrees Fahr.

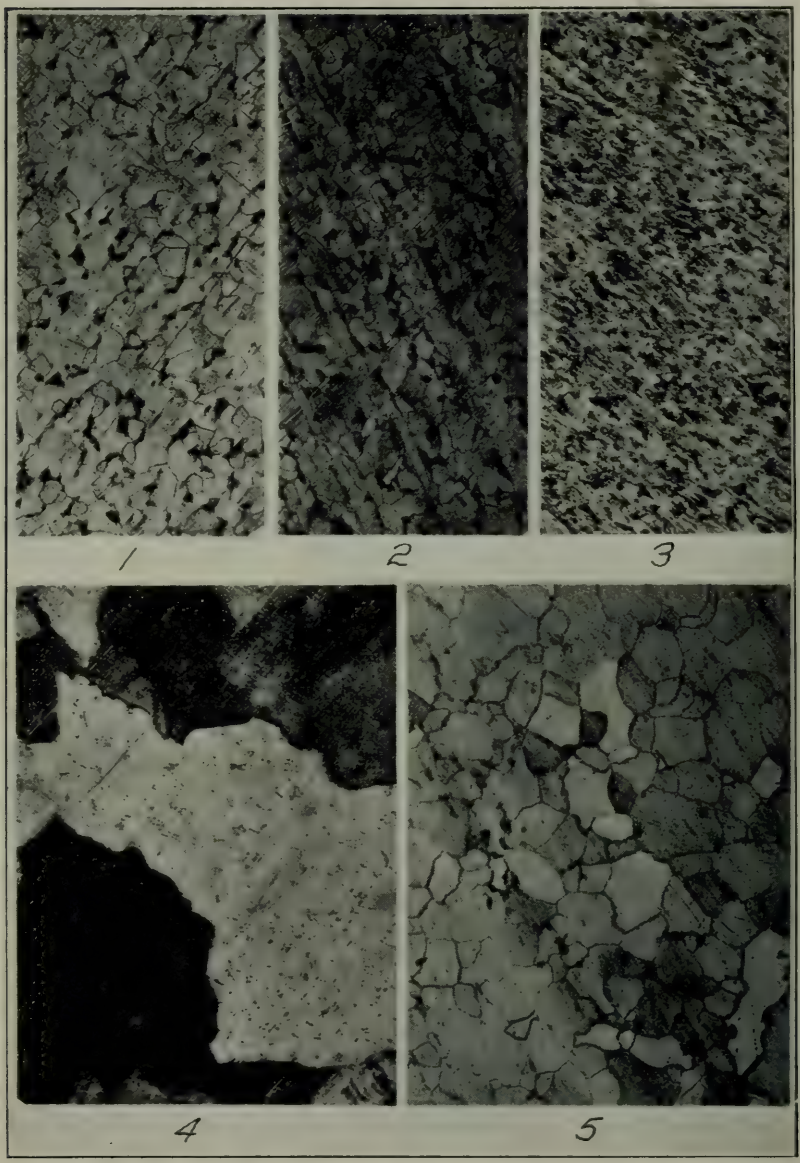

Fig. 1—Photomicrograph of Annealed 0.03% Carbon Steel Before Cold Working or Heat Treating. Fig. 2—Photomicrograph of 0.08% Carbon Steel After a 7.5% Reduction by Cold Work. Fig. 3—Photomicrograph of a 0.08% Carbon Steel After a Cold Reduction of 66%. Fig. 4—Photomicrograph of 0.08% Carbon Steel Annealed at 1250 degrees Fahr. for 8 hours after a Cold Reduction of 7.5%. This Enormous Grain Growth was Developed by Annealing. Fig. 5—Photomicrograph of 0.08% Carbon Steel Annealed for 8 hours at 1450 degrees Fahr. after a Cold Reduction of 14%. All Photomicrographs × 100.

Metallographic Observations

Photomicrograph, Fig. 1, shows a specimen of annealed 0.08 per cent carbon steel. It will be noted that the pearlitic particles show no evidence of cold work. Moreover, the ferrite grains are equi-axed.

Fig. 2 shows the effect of cold rolling a 0.08 per cent carbon steel. The specimen received a reduction in thickness equivalent to 7.5 per cent. This specimen was critically strained. The elongated grains are especially noticeable in the pearlitic areas. Note particularly the appearance of the metal in the "as-rolled" condition, free from heat treatment.

Photomicrograph, Fig. 3, shows the effect of excessive cold work on 0.08 per cent carbon steel, in which a reduction in thickness of 66 per cent has been effected. The highly strained condition of the metal is plainly evident, the crystals being elongated in the direction of rolling. The specimen has been strained beyond the "critical," and the crystals have assumed a ropey appearance resembling fiber. Hence, annealing within the danger zone (1150—1450 degrees Fahr.) will not develop crystalline growth.

The microstructure of a 0.08 per cent carbon steel which has been cold rolled to a reduction in thickness of 7.5 per cent is shown in Fig. 4. The specimen was annealed for 8 hours at 1250 degrees Fahr. The photomicrograph shows the enormous grain growth, which thermal treatment developed. It should be borne in mind, however, that a critical strain (namely 7.5 per cent draft) was a pre-requisite to the creation of this structure.

Fig. 5 shows the microstructure of a 0.08 per cent carbon steel cold rolled to a 14 per cent draft. This specimen was annealed at the upper limit (1450 degrees Fahr.) of the danger zone for 8 hours. The photomicrograph (Fig. 5) shows a transition stage in the specimen as evidenced by the semi-growth of the crystals. They are neither excessively large nor minute.

Photomicrograph, Fig. 6, is that of a 0.08 per cent carbon steel having had a 66 per cent draft and then annealed within the hazardous range, namely 1250 degrees Fahr. for 8 hours. It will be observed that no grain growth has taken place. This

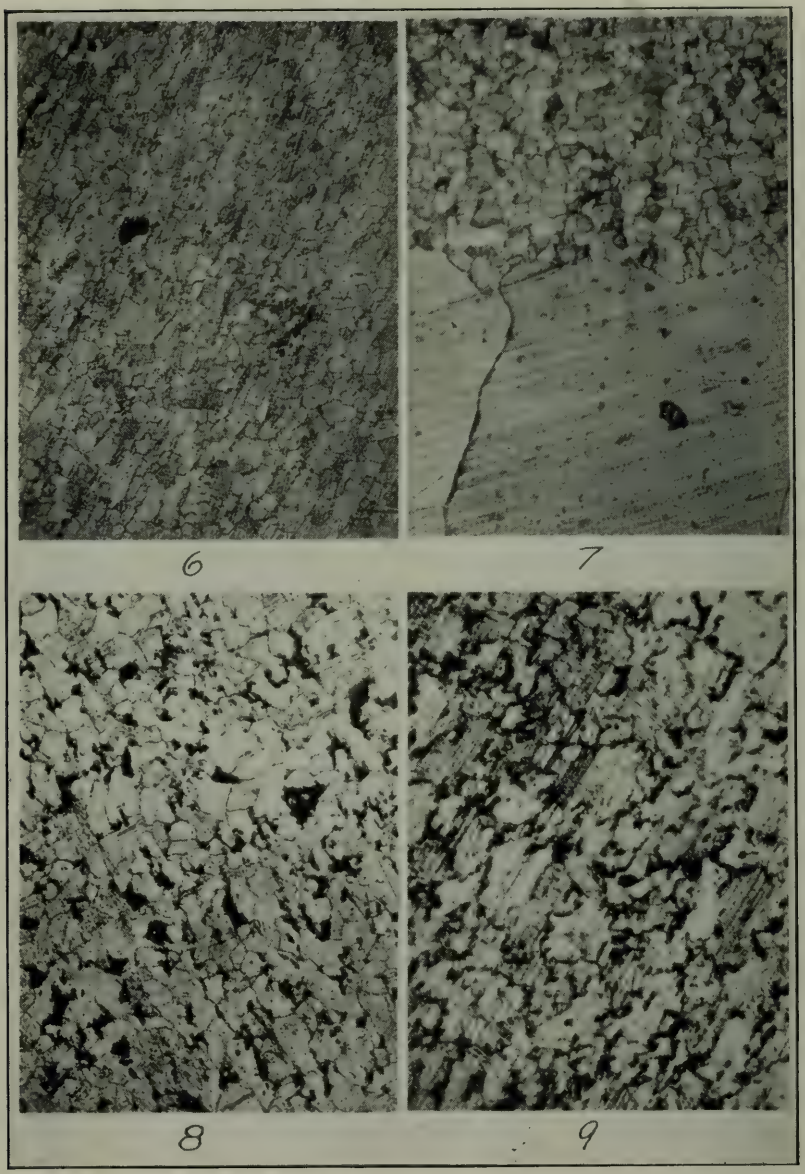

Fig. 6—Photomicrograph of 0.08% Carbon Steel Annealed for 8 hours at 1250 degrees Fahr. After a Cold Reduction of 66%. Ferrite Particles are Returning to Normal while the Pearlite Remains Elongated. Fig. 7—Photomicrograph of 0.08% Carbon Steel Annealed 8 hours after a Cold Reduction of 7.5%. Apparently the Metal has been Subjected to an Inequality of Pressure. Fig. 8—Photomicrograph of 0.08% Carbon Steel Critically Strained (14%) Annealed at 1500 degrees Fahr. for 8 hours. Fig. 9—Photomicrograph of 0.15% Carbon Steel Annealed at 1250 degrees Fahr. after a Cold Reduction of 14%. All Photomicrographs × 100.

steel was annealed at a temperature which would have developed crystalline growth if the metal had been critically strained. The only influence which the thermal treatment exerted on this specimen was to convert the elongated ferrite areas to their former equi-axed condition. The pearlitic particles remain unaffected. A similar structure was observed in specimens which were reduced in thickness as follows:

Per Cent	Per Cent	Per Cent
19	48	
21	58	75
29	61	77
35	68	80
40	72	

Fig. 7 shows an interesting side light on the development of crystalline growth in a 0.08 per cent carbon steel which was reduced in thickness 7 per cent, and annealed at 1250 degrees Fahr. for 8 hours. Apparently, the metal has been subjected to an inequality of pressure.

The explanation of this erratic performance may be attributed to the fact that the force of cold rolling was not sufficiently uniform to cause all of the grains to become critically strained. It may be remarked that where a specimen receives a tapering deformation, there always exists a sharp line of demarcation differentiating the critically strained from the understrained grains.

Photomicrograph, Fig. 8, shows a 0.08 per cent carbon steel critically strained (14 per cent) and annealed at 1500 degrees Fahr. for 8 hours. Although the metal has been critically strained, crystalline growth failed to develop because the metal was subjected to a temperature beyond the upper limit (1450 degrees Fahr.) of the hazardous zone.

Fig. 9 is a photomicrograph of a specimen of 0.15 per cent carbon steel cold rolled to 14 per cent reduction in thickness, annealed at 1250 degrees Fahr. for 8 hours. It will be observed that the metal contains a relatively large percentage of pearlite. The presence of this microconstituent stands in the way of the ferrite grains and prevents them from merging to form crystalline growth.

Conclusions

In formulating a summary of this work it has been subdivided into 5 parts.

I. The degree of draft which will produce a critical strain in cold rolled steel occurs when the metal receives a reduction in thickness of 7.5 to 15 per cent inclusive.

II. In critically strained cold rolled steel the growth producing range is between 1150 and 1450 degrees Fahr.

III. The aforementioned temperature limits vary according to the carbon content of the metal, namely;

Carbon per cent	Temperature degrees Fahr.
0.08	1150-1450
0.10	1250-1450
0.13	1300-1450

IV. A draft of 7.5 to 15 per cent should be avoided in cold rolled steel which is used for vital parts. This procedure will prevent crystalline growth in the event that the parts are subjected to service temperatures which lie within the danger zone (1150 to 1450 degrees Fahr.).

V. Increasing the carbon content of the metal beyond 0.18 per cent will effectively prevent crystalline growth regardless of the degree of strain or temperature.

CARBURIZATION OF STEEL

By B. F. Shepherd

Abstract

This paper specifically studies the continued use of carburizing compounds as it affects the character of the case produced. The influence of increased carburizing temperature, the effect of time variation, the influence of time and temperature upon the character of the case and the relationship in carburized and hardened chrome-vanadium steel between scleroscope hardness, carbon content and penetrability as measured by the Brinell method at different zones in the case, is studied in detail. Numerous curves and data sheets accompany this paper.

Introduction

CARBURIZATION, cementation or case-hardening is the term used for any method of increasing the carbon content of a piece of iron or steel, without melting it. The action takes place with the greatest intensity on the surface, gradually forming an outer zone or case which becomes wider as the absorption of carbon continues. Two distinct applications are made of this phenomenon, one called total cementation, when the piece is completely changed to a high carbon steel, and the other partial cementation. In the latter case, the carburizing action is checked or stopped when the zone or case, is of the desired depth and carbon content. The former is used for the manufacture of special quality high carbon tool steel and the latter with which we are principally interested for the heat treatment of machine parts, to withstand difficult service conditions.

Historical

The first mention of the carburization of iron or steel was published in the year of 1540, the method described, consisting in heating billets of soft iron for a long period of time in molten

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A paper presented before the Eastern Sectional meeting of the Society, Bethlehem, Pa., June 14, 1923. The author B. F. Shepherd is in the metallurgical department of the Ingersoll-Rand Co., Phillipsburg, N. J.

cast iron. The soft iron, being much lower in carbon content than the cast iron, absorbed carbon from it.

In the sixteenth century many processes were used for the superficial or surface hardening of finshed objects. During this superficial or surface hardening of finished objects. During this was later forged to shape. The 'secret formulas' for these processes were handed down from father to son, and it was not until 1720 that the French scientist Reaumer made a scientific investigation of the process. In 1740, Benjamin Huntsman melted in a crucible, Swedish bar iron which had been increased in carbon by cementation, and produced a high grade steel. Other methods of manufacturing steel at lower prices gradually forced this process from the market, but it is still used in a very small extent in England.

General

Owing to the difficult service requirements to be met by modern machinery, the use of case-carburizing as a method of heat treatment has increased very materially. The process creates a steel capable of being made extremely hard and wear-resistant on the outside and having a strong, tough, inner portion or core. This type of structure is suitable for parts which are required to stand considerable shock and friction. Parts which are required to be hardened only on portions of the total area may be rough machined and carburized and the higher carbon regions removed, by machining it from the areas which are desired soft. The added advantage of being able to machine a softer and cheaper material and subsequently making it surface hard by carburizing, materially lessens the cost of the part. Engineers often lose sight of the problems encountered in the heat treating department and design parts of complicated form which are to be hardened on the surface. If these parts are made of high carbon tool steel, the hardening operation usually becomes hazardous due to the tendency of complicated sections to crack during the quenching operation. The use of a carburizing steel makes the operation less hazardous from the standpoint of tool breakage.

Carburization depends upon the ability of iron and steel to absorb carbon when heated in contact with a carbonaceous material. The primary factors which influence the results are,

the length of time the piece is exposed to the temperature, the temperature, the carburizing material, and the composition of the steel. As a general rule, the higher the temperature and the longer the time, the deeper will be the case.

The carburizing steels in general use are selected according to the service requirements of the parts which are to be made from them. The selection of these steels should be studied very carefully. The carburizing process cannot remove imperfections, irregularities or faults in the steel. It will magnify them. As a general rule parts should not be made of a carburizing steel if it is possible to obtain satisfactory service from an oil or water hardening steel properly heat treated. The equipment needed for the carburizing operation, the materials used, the time consumed and the careful supervision required cause a heavy labor and overhead charge resulting in an increased cost of the finished part.

The type of steel, the heat treatment which the part is to receive, and the machineability of the steel are of considerable importance. Several well known types of steel should be adopted as standard. It is usually desirable that these should conform to the specifications of societies such as the Society of Automotive Engineers and the American Society for Testing Materials. In some special cases it may be necessary to specify a special analysis steel, but adherence to a few standard steels will result in better service from the steel manufacturer when business is booming and steel is hard to obtain. It also means that less steel will be required for stock purposes as the sizes for the various parts will duplicate and a smaller quantity in stock will meet all demands. A better knowledge of methods of handling in the heat treating department will result, as familiarity with certain well known types increases.

Each type of steel should be procured from several manufacturers, and after experience has shown the quality which each has furnished they should be graded and purchased accordingly. The steel, when received should be carefully inspected for chemical composition, surface, size, seams and occasionally fracture and micro-structure.

Carburizing Materials and Methods

The method of carburization varies with the cement or

carburizing compound used. The different types of carburizing compounds may be roughly classified as solid carburizers, which represent the great bulk of commercial carburizers; liquid carburizers, gases and mixed cements. The latter term is used by Giolitti and consists of a combination of carbon monoxide gas and charcoal.

The solid cements are usually granulated materials such as wood charcoal, raw bone, charred bone, bone impregnated with oils, charred leather, coke and coal compounds impregnated with an energizer. Liquid cements are usually molten cyanogen salts.

The purpose of this paper is to discuss the results of certain tests made upon several commercial solid carburizing compounds for the purpose of ascertaining and correlating certain data which are factors surrounding the carburizing operation. These data have been illustrated, mainly by carbon concentration diagrams and also show the difference in characteristics, weight, cost, etc., of eight different commercial compounds. The factors studied are:

1. The effect of continued use of the compounds under test upon the depth and character of the case produced in a chrome-vanadium steel.

2. The influence of increased carburizing temperature upon the depth and character of the case produced in the same type steel by these compounds.

3. The effect of variation in time upon the depth and character of the case produced by a commercial compound on two steels, a simple carbon and a chrome-vanadium steel.

4. The influence of time and temperature upon the depth and character of the case produced by a shop mixture of a well known commercial compound on a chrome-vanadium steel.

5. The relation in a hardened chrome-vanadium steel between scleroscope hardness, carbon content and penetrability as measured by the Brinell method at different zones in the case.

6. The depth and character of case produced in a chrome-nickel steel as compared with a chrome-vanadium steel.

Procedure

The method of procedure employed is as follows: The test pieces for each series run were 5 inches long and from the same

bar of steel. The bar was a $2\frac{1}{4}$-inch round and the test pieces were machined and finished to 2 inches round, by grinding. The short stocky bar minimized the possibility of distortion and

Fig. 1--Type of Carburizing Box Used in these Tests.

the large diameter gave a sample with an 0.005-inch cut sufficiently ample to permit of a representative chemical determination. The pieces were packed with a $\frac{1}{4}$ cubic foot, loose measurement, of compound in an alloy carburizing box $12\frac{1}{2}$x $6\frac{1}{2}$x7 inches deep inside dimensions, the recessed lid of the box being luted with clay. The type of box used is shown in Fig. 1.

Eight hours were taken to heat the boxes through to 1600

degrees Fahr., other temperatures in proportion. When the boxes were held for the number of hours noted, they were removed and allowed to cool in the atmosphere. The temperature was measured with a standardized potentiometer recorder, held to within plus or minus 15 degrees Fahr. and checked during the

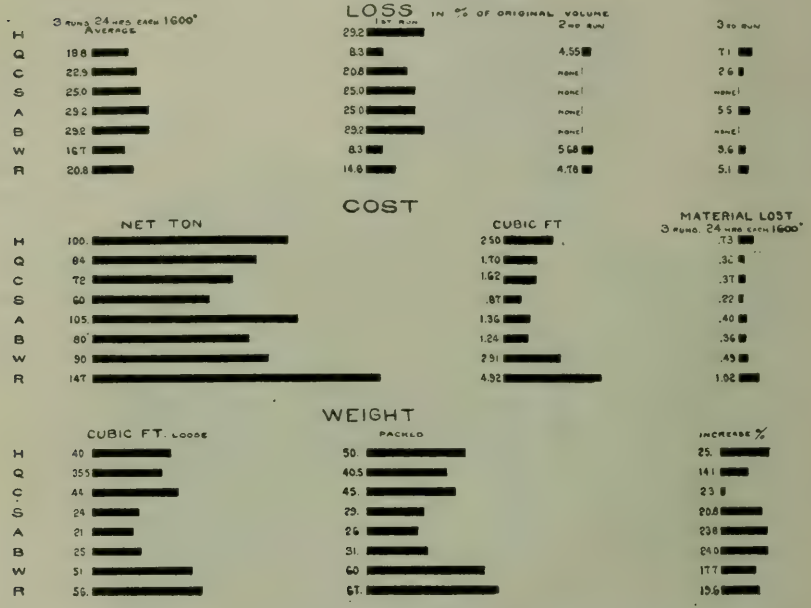

Fig. 2—Shows the Difference in Weight and Cost of Eight Different Commercial Carburizers Together with the Loss of Compound Obtained in Three Runs of 24 Hours Each.

run with a portable potentiometer. An additional thermocouple was in the furnace during the entire period of the heat, spaced 4 to 5 feet from the first thermocouple, this being used to check the uniformity of the furnace temperature. The furnace was fuel oil-fired and of a construction which ensured uniform heating of the boxes which were carefully spaced on and held off of the furnace hearth by legs 1½ inches high.

Weight, Cost and Shrinkage

Fig. 2, shows the difference in weight and cost of eight different commercial carburizers together with the loss of com-

pound obtained in three runs of 24 hours each after heated through at 1600 degrees Fahr.

The lower set of figures show the great difference existing in the specific gravity of commercial compounds. As these materials are purchased by weight and used by volume the lightest compound will be the cheapest as it will fill more boxes. Of two compounds having the same carburizing properties, price and specific gravity, the one which does not settle excessively when packed will be the cheapest. Compounds which settle excessively when packed must be used carefully or part of the work may be uncovered when the box is placed in the furnace.

The middle set of figures shows the relation between the initial price, the price per cubic feet and the cost of the material lost by shrinkage during three runs. Compound "S" was the cheapest compound although the specific gravity was about the same as compounds "A" and "B."

The initial low price of this material was not made without reason, as the carbon concentration curves show it to be very erratic and to actually produce decarburization in one run. It is a cheap coke-charcoal compound, impregnated with energizer and made to sell. Compound "A" is lighter than "B" and has approximately the same percentage increase in weight when packed. The difference in weight brings the price per cubic foot very close to that of "B."

The influence of the increase in weight when packing a compound is seen in the comparison of "C" and "Q." The latter has the highest price per ton but is also the lighter and comparison on this basis makes it the cheaper, i. e., $1.58 for "C" against $1.49 for "Q." It has a larger increase in weight when packed and this causes the costs to be reversed and the compound with the low percentage of weight increase is found to be the cheaper of the two, i. e., $1.62 for "C" against $1.70 for "Q." The influence of weight of the compound is seen in the heavier compounds showing that the market price is not an indication of the cost as used.

A comparison of the shrinkage data or loss of compound seen in the top set of figures shows a great variation. It is much better for a compound to shrink gradually than to have a high initial shrinkage. The possibility is always present of some of

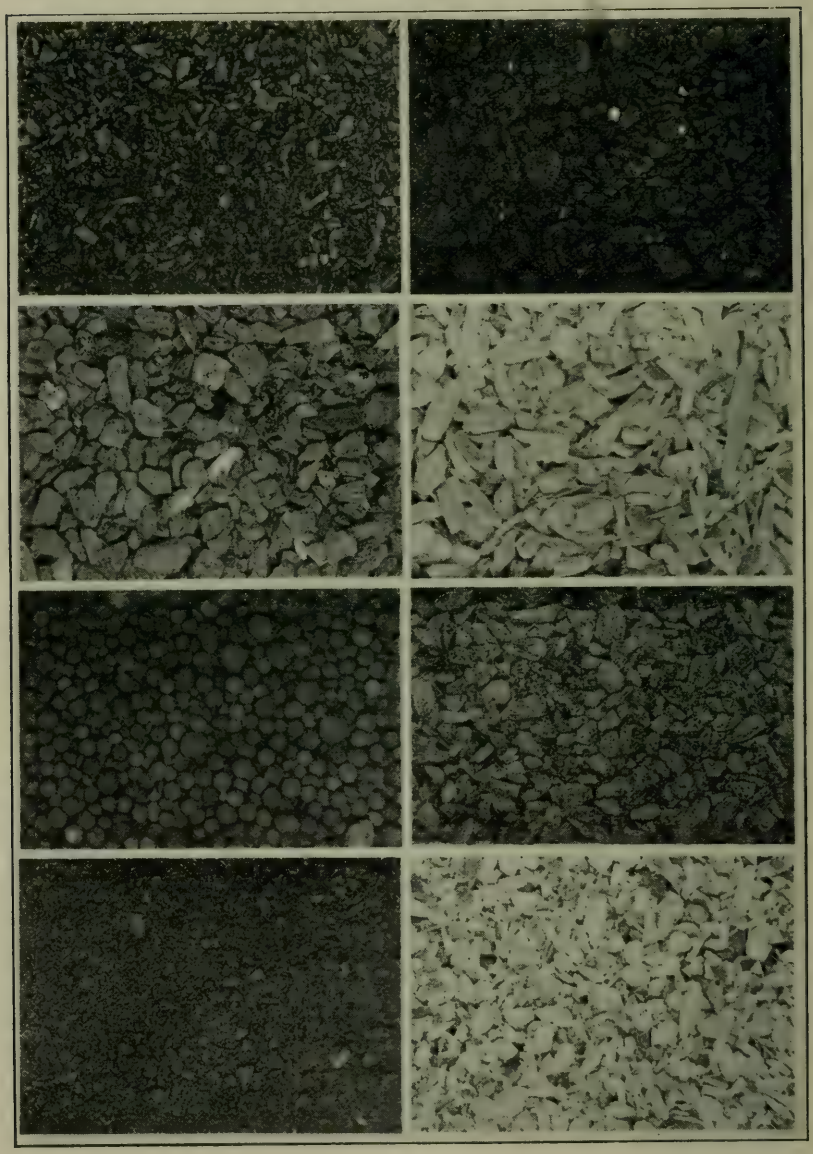

Fig. 3—Photograph of the Eight Different Commercial Carburizing Materials Used in this Test.

the work being exposed by the shrinkage of the compound, as the shop mixture usually is composed of several parts old compound to one of new. The packer may find he has used up all of his shop mixture and in order to fill the last few boxes may use all new compound, placing the same quantity of pieces in each box. Some of these will be exposed by the shrinkage of compound having a high initial shrinkage. In such cases, the top layer of parts should not be placed in the box and plenty of excess compounds should be used. This high shrinkage also adds to the cost of the compound.

Compounds Used in Test

The compounds used in this test are shown in Fig. 3. A compound should be reasonably free from dust. Dusty compound is disagreeable to the workman, causes a high compound loss cost and has a tendency to choke the compound, by keeping the gases away from the work. If the dust is composed of energizer it will settle to the bottom. The compound should not pit the steel. Some compounds are so heavily charged with energizer that a chemical action takes place between it and the steel and the finish of the latter is damaged. This condition took place with compound "C" and would prove exceptionally objectionable if this compound were used for pack hardening.

It might be mentioned at this time that a desired quality in a carburizing material is good thermal conductivity. In general, these materials are poor heat conductors, and the time taken to heat to temperature is a large proportion of the total time used in the production of thin cases. Some compounds absorb heat at certain temperatures to complete internal reactions. Raw bone contains a high percentage of moisture and volatile matter which must be driven off when first heated. Bone used once heats much faster than new bone and the desired case can be obtained in a shorter total time. Some compounds are impregnated with oil and a considerable amount of heat is required at 500-600 degrees Fahr. to volatize the oil. At these temperatures, the hydrocarbon gases evolved are not of carburizing value.

Determination of Carbon Content of Case

In order to determine the carbon content of the carburized zone, the test pieces were placed in a lathe, the surface polished

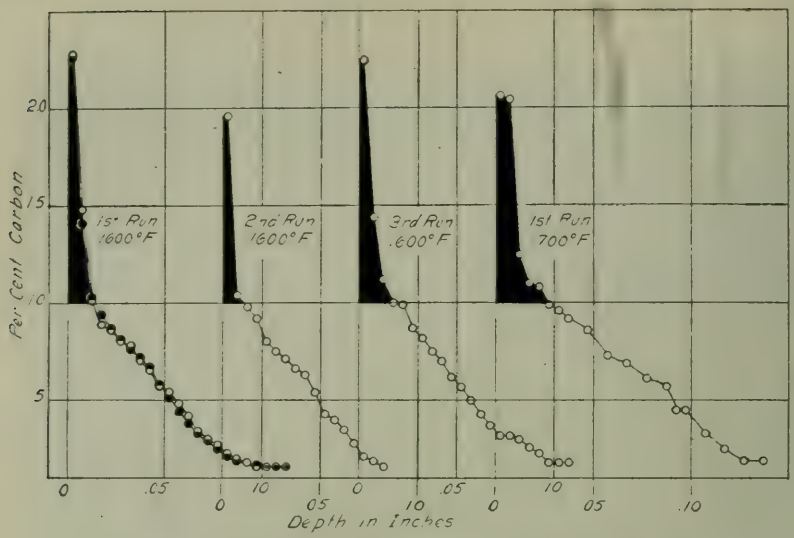

Fig. 4—Curves Showing Carbon Penetration of Compound "C".

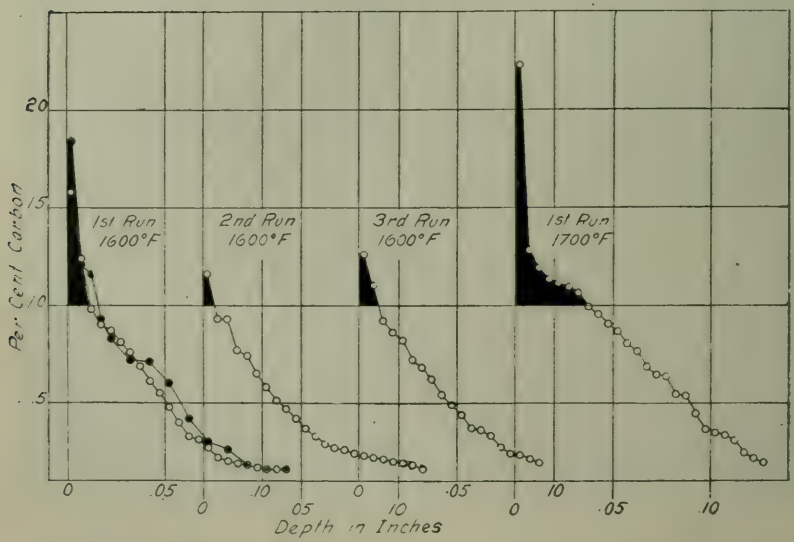

Fig. 5—Curves Showing Carbon Penetration of Compound "Q".

with fine emery paper and all traces of foreign material removed, the corners were cut back ¼ of a inch to remove the increased depth of case at these regions and cuts of 0.005 inches thick by 4 inches long were removed with a high-speed steel tool. The chips were mixed and analyzed for carbon by the standard combustion method. It was necessary to use extreme care in removing the outer layers on the chrome-vanadium steel as the combination of the high carbon with the alloys present had made these regions self hardening upon slow cooling. Many of the determinations plotted are averages of several check analyses.

Effect of Continued Use of Compounds

The different carburizing compounds shown in Fig. 3, were used in three separate runs, the time being 24 hours for each run at 1600 degrees Fahr. New compound was used for the first run and no new compound was added. A subsequent test was run at 1700 degrees Fahr. for 24 hours at temperature using new compound. The steel in each case was chrome-vanadium, S. A. E. 6120. The individual curves plotted from each run are shown in the accompanying diagrams.

The curve for the first run of compound "C," Fig. 4, is composed of the separate analysis of two samples which were in the box. This shows the uniformity of the specimens packed in the same box. The extremely high carbon content in the hyper-eutectoid zone is characteristic of the results obtained with each material. In each of the accompanying curves the zone above 1.00 per cent carbon is blackened for easier identification. The increase in depth of this zone on increase of temperature to 1700 degrees Fahr. is also noticable. It is seen that continued use of this compound does not effect appreciably the percentage and depth of carbon over 1.00 per cent produced in the hyper-eutectoid zone.

The carbon penetration results obtained in using compounds Q, W, S, A, B, and R are shown in Figs. 5, 6, 7, 8, 9, and 10. The summary of the results are shown in Fig. 11.

Compound S, Fig. 7, second run at 1600 degrees Fahr. actually has caused a decarburization of the specimen.

The curves, Fig. 8, show the results obtained in using compound A, and S. A. E. 6120 steel. While duplicate specimens

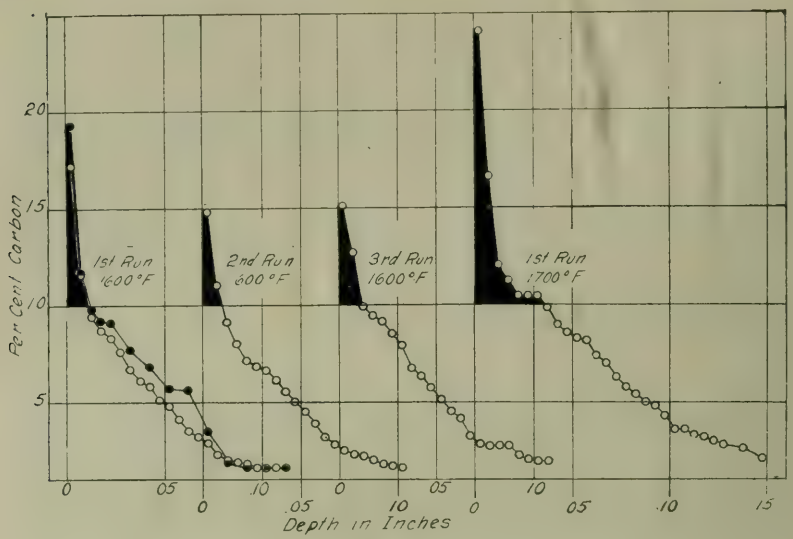

Fig. 6—Curves Showing Carbon Penetration of Compound "W".

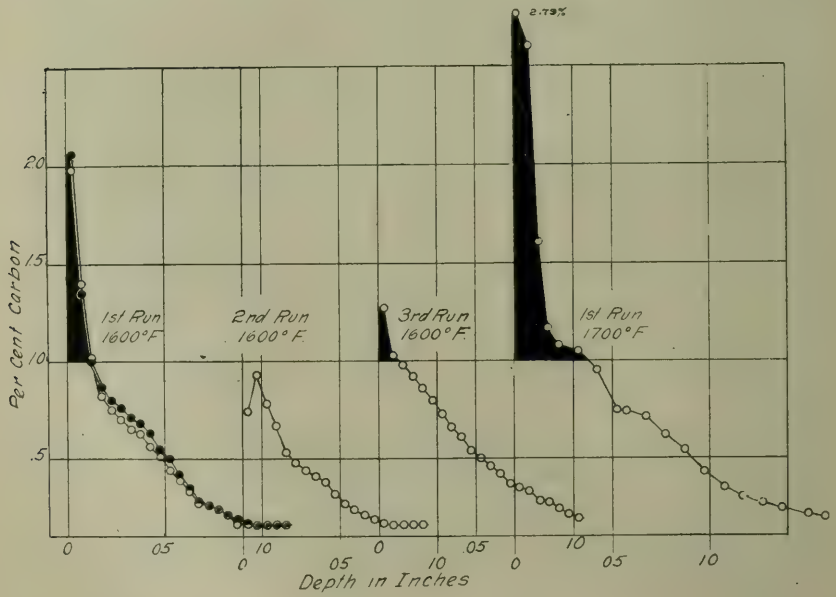

Fig. 7—Curves Showing Carbon Penetration of Compound "S".

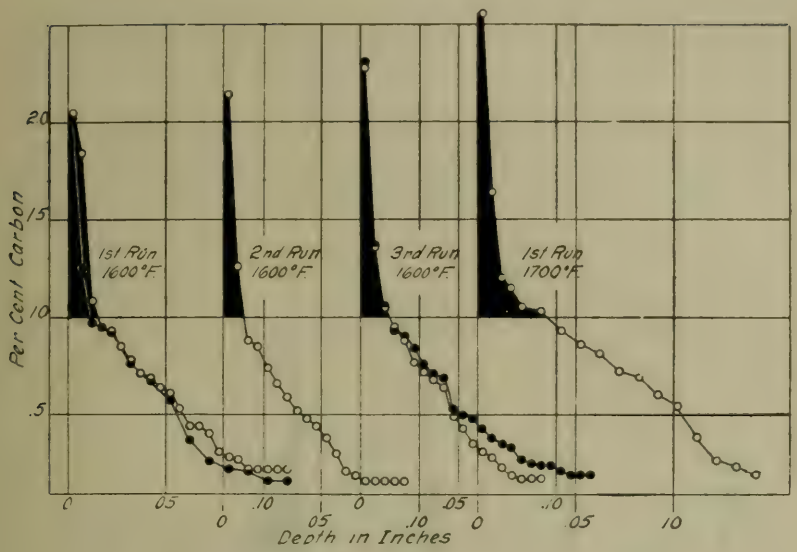

Fig. 8—Curves Showing Carbon Penetration of Compound "A".

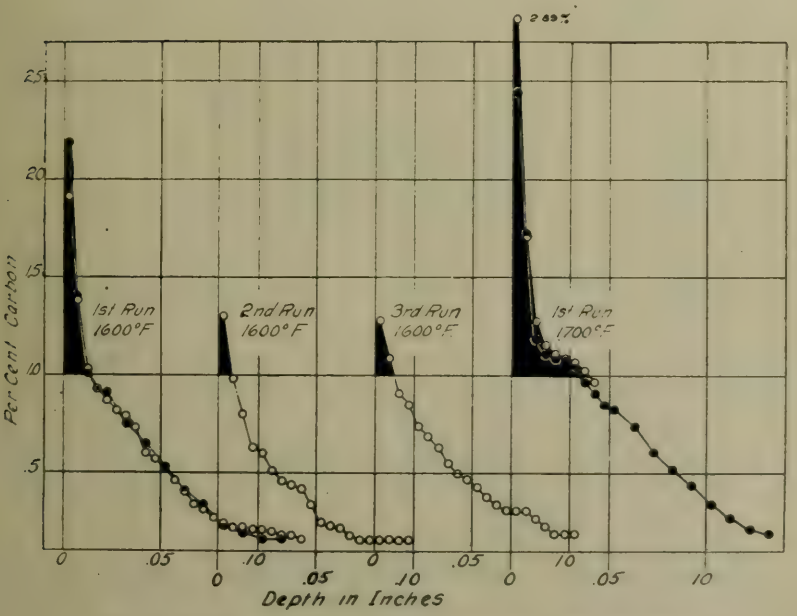

Fig. 9—Curves Showing Carbon Penetration of Compound "B".

were placed in each box it will be noticed that they have been used only on the first run. The second specimen in the third run of this compound was analyzed for check purposes.

The tendency of the increased carburizing temperature to build up carbon in the exterior of the case and render the graduation with the core more abrupt should be noticed. The carbon

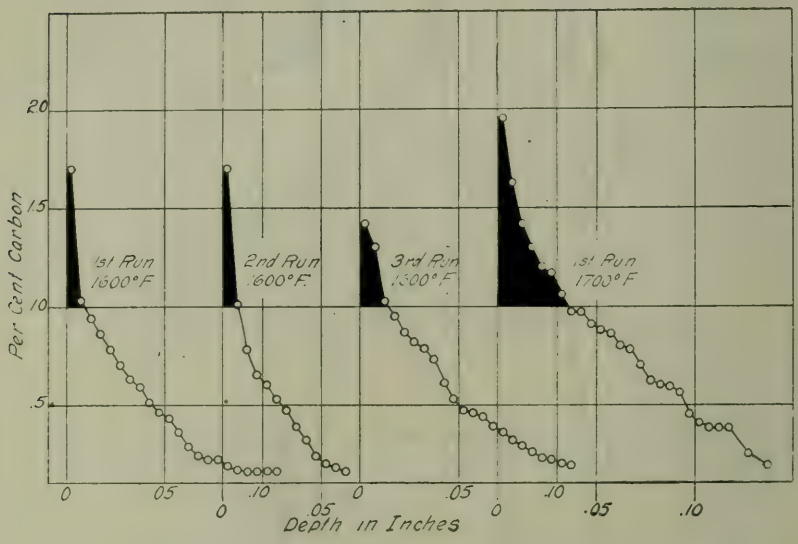

Fig. 10—Curves Showing Carbon Penetration of Compound "R".

analysis on the exterior zone of the 1700 degrees Fahr. run using compound B, Fig. 9, is the highest determined. This specimen was reversed and replaced in the lathe and nine new cuts taken from the end which had been held by the lathe dog. The results obtained checked very closely to those taken previously.

Compound H was only used for one run, but it was tested at a different time. The condition of the tests were the same, however, and the results are thought to be comparative. The curve is shown in Fig. 12.

Fig. 11, shows in graphic form the summary of the results obtained in the tests. The depth obtained with each compound together with average depth obtained on the three runs is shown.

The increase in the depth of the case and the depth of the region containing over 1.00 per cent carbon is readily seen.

Carbon and Alloy Steel Penetration

The effect of variation in time in this characteristic together with effect upon depth of case is seen on the test of a simple car-

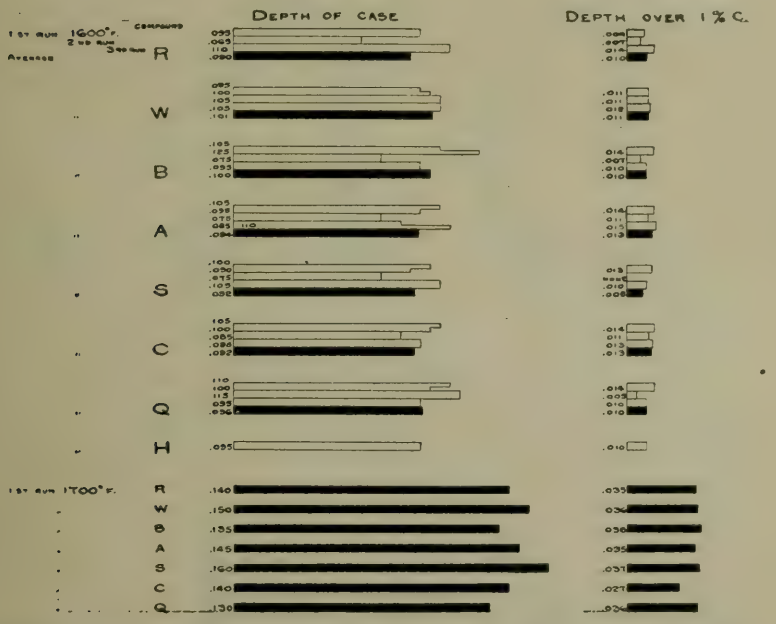

Fig. 11—Graphic Summary of Results Obtained in Figs. 4-10. The Depth of Penetration Obtained with Each Compound Together with the Average Depth Obtained on Three Runs is Shown.

bon steel, S. A. E. 1015 and a chrome-vanadium, S. A. E. 6120, Fig. 12. These curves were made with compound H at 1600 degrees Fahr. The effect of increased time at temperature, is to increase the depth of case and concentration of carbon over 1.00 per cent carbon in the chrome-vanadium steel; carbon steel in the same proportions. The carbon steel is not, however, subject to excessive concentration of carbon in the hyper-eutectoid zone and does not absorb carbon as readily as the alloy steel.

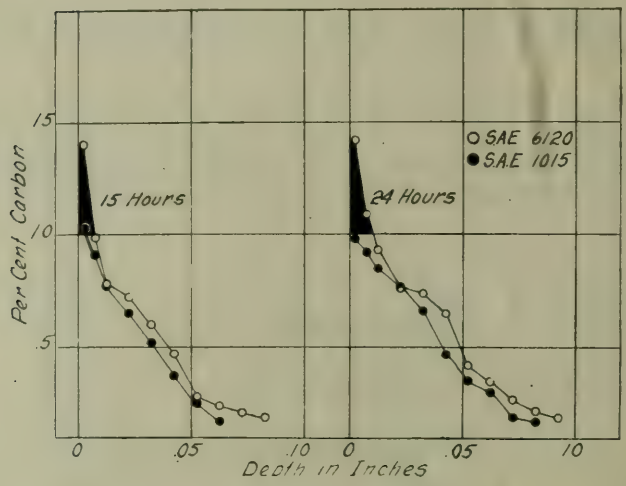

Fig. 12—Curves Showing Carbon Penetration of Compound "H".

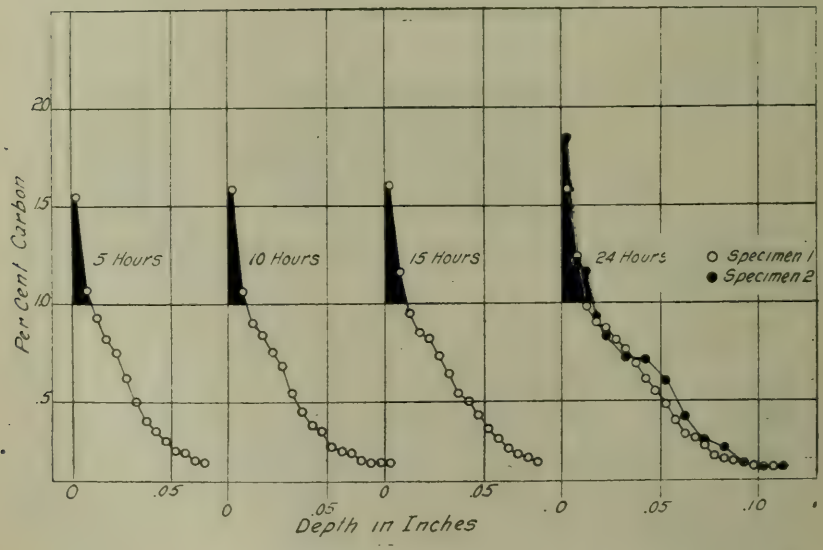

Fig. 13—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1600 Degrees Fahr.

Effect of Time and Temperature Upon Depth of Case Using Shop Mixtures of Compounds

The effect of temperature of carburization is to increase the depth of case and the depth of excess carbon in the exterior zones. The curves in Figs. 13, 14, 15 and 16 were obtained with a shop mixture, 3 parts old to 1 part new compound, on a chrome-

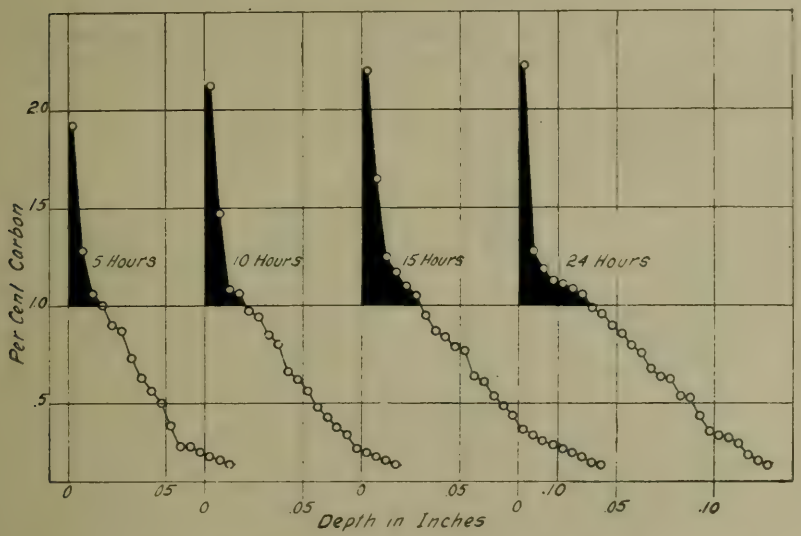

Fig. 14—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1700 Degrees Fahr.

vanadium steel S. A. E. 6120 at carburizing temperatures of 1600, 1700 and 1800 degrees Fahr. The compound used was "Q." The time given in all cases is after the box was heated through at the carburizing temperature. The 24 hour run at 1600 and 1700 degrees Fahr. were taken from the previous data and were made with new compound. Fig. 13, shows the results obtained at 1600 degrees Fahr., Fig. 14 at 1700 degrees Fahr. and Fig. 15 at 1800 degrees Fahr.

Fig. 16, is a general curve compiled from Figs. 13, 14 and 15, which shows this steel to have a tendency toward the 'critical penetration' described by Bullens and seems to show that carbon is absorbed slowly and gradually at low temperatures. An increase

in temperature tends to force carbon into the steel very quickly. A certain period of time, which is shorter than the higher carburizing temperature, is finally reached where the diffusion of the carbon into the interior proceeds more slowly with consequent slowing up of the penetration obtained with a given time and increase in percentage of carbon in the exterior zones.

The same depth of case was obtained with 3 hours at 1800 degrees Fahr. as was obtained with 10 hours at 1700 degrees Fahr. and 24 hours at 1600 degrees Fahr. The percentage loss in volume of the compound increased very slowly with increase in the temperatures.

The compound showed the following volume loss:

Compound	Per cent Loss	Time in Hours
1600 Degrees Fahr.		
Shop Mixture Q	16.67	5
Shop Mixture Q	17.83	10
Shop Mixture Q	17.83	15
New Compound Q	8.3	24
1700 Degrees Fahr.		
Shop Mixture Q	16.67	5
Shop Mixture Q	16.67	10
Shop Mixture Q	16.67	15
New Compound Q	19.8	24
1800 Degrees Fahr.		
Shop Mixture Q	17.86	3
Shop Mixture Q	18.75	6
Shop Mixture Q	17.83	10

The tendency toward high carbon content near the surface is not entirely confined to chrome-vanadium steel. Fig. 17, shows the case produced with solid carburizer on a chrome-nickel steel S. A. E. 3320, 15 hours after being heated through at 1650 degrees Fahr. cooling in the box (this box being larger than that previously used, the dimensions being 9½x18x23 inches). By reference to the previous curves it is seen that the depth and character of the case produced are practically the same.

It might be noted at this time that the type of steel has a great influence upon the manner of distribution of the free carbides

in the hyper-eutectoid zone. In chrome-vanadium steels the carbide forms in tiny globules and spheroids, Fig. 18.

Simple carbon, nickel, and high-nickel low-chromium steels have a tendency to precipitate the carbide in the form of a network or needles unless the concentration is very high, Fig.

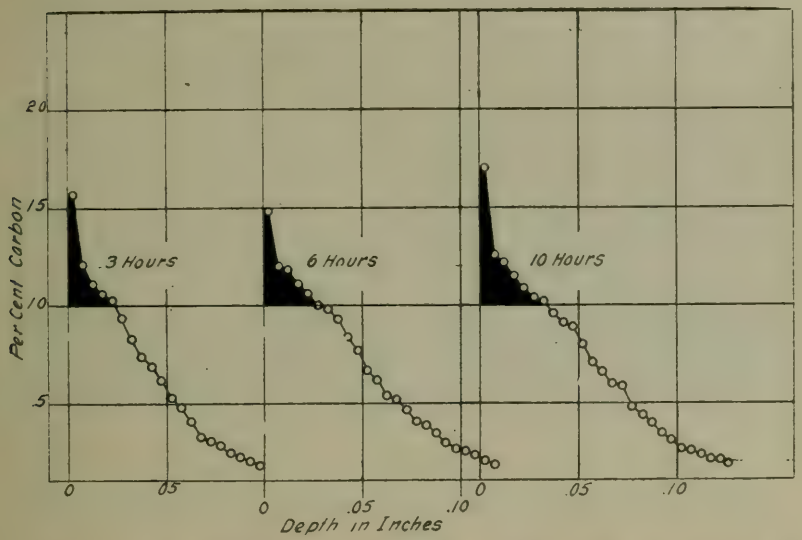

Fig. 15—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1800 Degrees Fahr.

19. An excessive depth of high carbon gives rise to a fracture which has a fiery ridge or rim of very crystalline material.

Fluctuations or variations in temperature cause an excess amount of carbide to desposit near the surface. This is due to the fact that a slight drop in temperature causes the steel to become supersaturated with carbide precipitating some of the carbides. As the temperature again rises, the steel absorbs carbon from the carburizing gas much quicker than it can redissolve the carbide which it has just precipitated. When this occurs, an excess of carbide is found near the surface.

This phenomenon is seen very often in nickel and chrome-nickel steels. If the concentration is comparatively high, the box will cool much more rapidly than the steel can diffuse the high carbon into the interior and an excessive carbon concentration

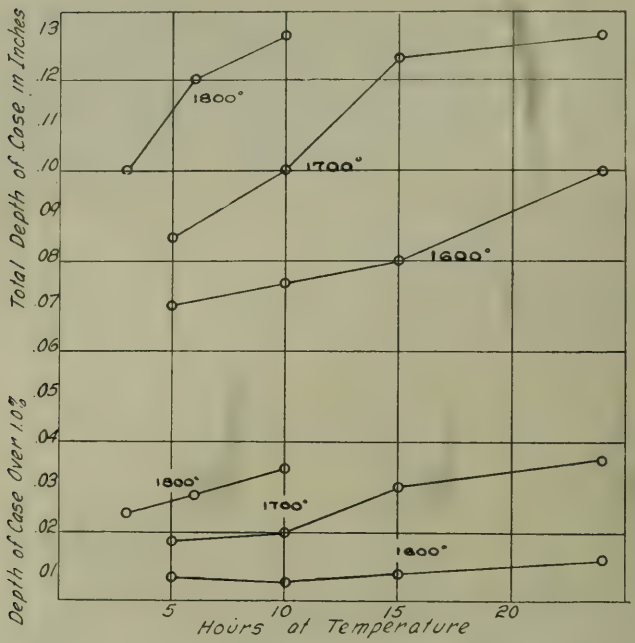

Fig. 16—General Curve Compiled from Figs. 13, 14 and 15.

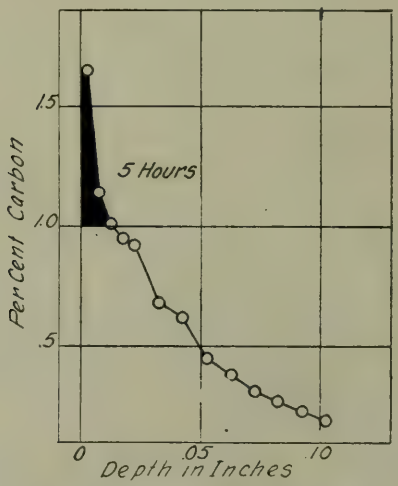

Fig. 17—Shows the Case Produced with Solid Carburizers on a Chrome-Nickel S. A. E. 3320 Steel, 15 Hours after being Heated Through at 1650 Degrees Fahr.

on the outside is the result. This discontinuity gives rise to a fracture which has a fiery edge or a thin border or rim of very crystalline material. This rim is composed almost entirely of carbide which is the hardest constituent in steel. It cannot be

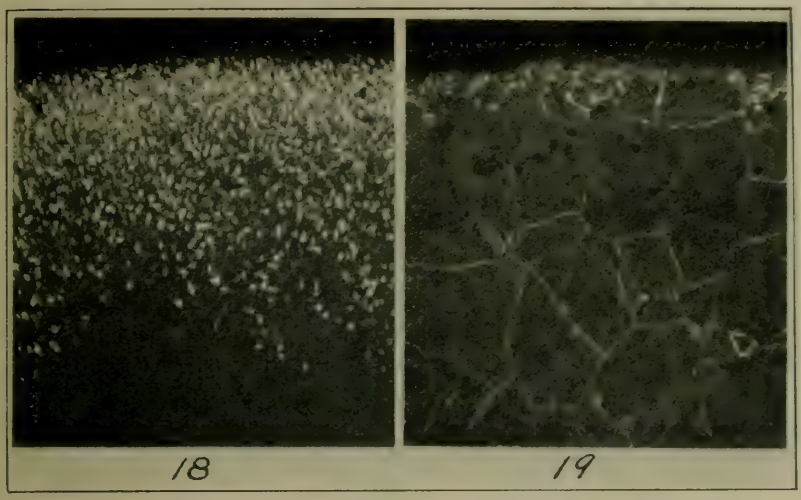

Fig. 18—Photomicrograph of Chrome-Vanadium Steel Showing a Concentration of Tiny Globules Near Surface. Fig. 19—Photomicrograph Showing Net-work of Carbides Near Surface of Carburized Chrome-Nickel Steel.

softened by tempering and is very brittle. Fig. 19, shows this type of zone on a chrome-nickel steel.

Cases of this type are subject to enfoliation or splitting off under shock, local heating caused by grinding, quick tempering or heating for hardening, etc. The face breaks off in flakes on a line parallel to the surface corresponding to the line of separation of the high carbon and eutectoid zone. The high carbon zone cannot deform on account of its intrinsic hardness and rigidity. Liquation is the term used for the separation of the normal and high carbon zone. Enfoliation is the term used to splitting off of the high carbon area formed by this separation.

The micrographs shown by S. C. Spalding in his paper published in the August 1922 issue of TRANSACTIONS, illustrates the tendency of the excess carbides to assume a form which is peculiar to the type of steel.

Inspection of Finished Parts

The best method of determining the ability of a carburized part to withstand service is to place it in actual service. After finding a type of steel which treated in a definite manner will give satisfactory service, the next step is to reproduce that part. The best method of testing the carburizing operation is to examine

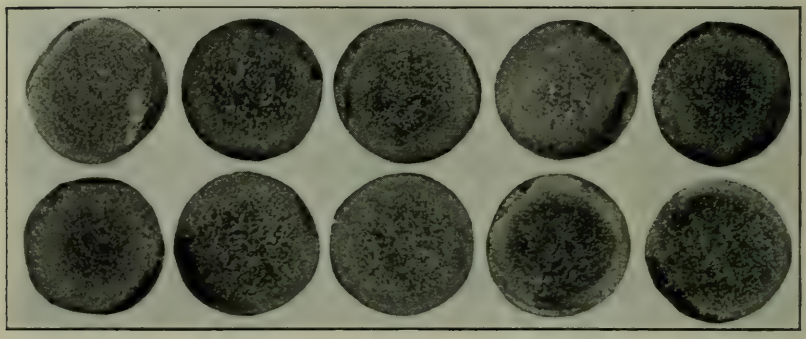

Fig. 20—Typical Fractures of Carburized Specimens of Steel. × 1½.

the case after subjecting the part to the standard heat treatment. This examination may be made by breaking the part for fracture or by taking sections from it and examining them under the microscope. The fracture test is easily made a routine inspection and gives a constant check on the quality of the material leaving the heat treating department. Fig. 20 shows some typical fractures.

Examination of the fracture should show whether the case is sufficiently deep, or the case and core are well refined. It is well to adopt a definite standard of depth which should be noted on the heat treatment instruction card. The method of breaking for fracture, gradually or quickly, across or with the grain alters the fracture and apparent depth of case considerably. Before rejecting a part on account of insufficient depth of case it should be broken several times.

The miscroscope is used as a supplementary means of inspection on special work. It is a matter of a few minutes for

the metallographist to polish, etch and examine a specimen for depth of case, distribution of carbon, etc.

The scleroscope and file are a means of testing the surface hardness. The sclerosope gives comparative results on the same material. The file hardness depends entirely upon the character

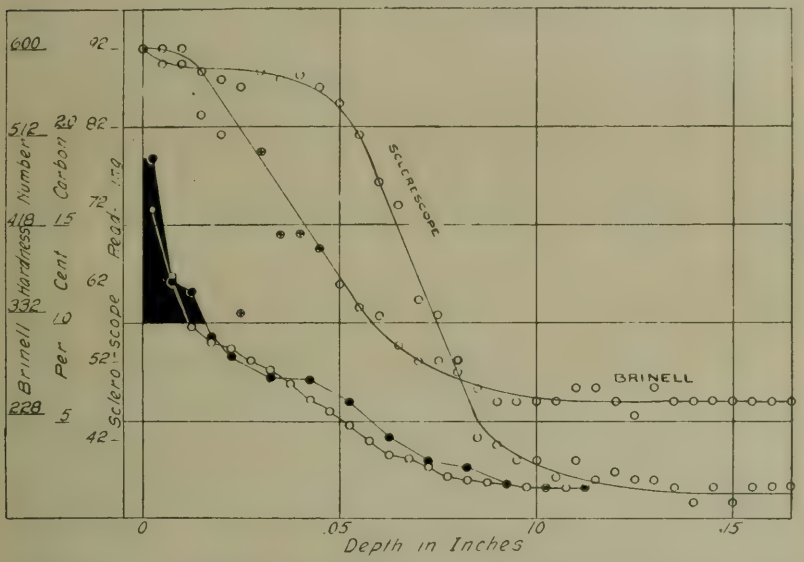

Fig. 21—Curves Showing the Relationship Between Scleroscope Hardness, Carbon Content and Penetrability Using Compound "Q".

and uniformity of the files used and the method of testing. The Brinell method is objectionable as it punches through thin cases and gives incorrect readings. Some plants use a pointed hammer to test the case. If a blow with the hammer does not cause fracture the case is assumed to be satisfactory.

Hardness

A slab about 7/8 inches thick was cut from a 2-inch round bar 5 inches long, of chrome-vanadium S. A. E. 6120 steel which had been carburized for 24 hours at 1600 degrees, Fahr., reheated to 1625 degrees Fahr. and quenched in oil, reheated to 1470 degrees Fahr. and quenched in brine. The specimen was ground parallel to the end of the specimen upon which hardness readings

were taken with scleroscope and Brinell machines, halfway between the center and circumference. Layers 0.005 inches thick were removed and consecutive hardness readings taken.

It is interesting to note (Fig. 21) that the scleroscope hardness remained rather high until the carbon content of the case dropped below 0.50 per cent carbon. The carbon content of the hyper-eutectoid zone apparently had not had any influence upon the hardness.

The case resisted penetration by the Brinell ball until a depth of 0.025 inches was reached. Between this and 0.045 inches a continuous circular crack appeared outside of and concentric with the indentation. Under this depth the case was sufficiently flexible to yield under the ball without cracking. The Brinell number on the opposite surface of the slab, about 7/8-inch distant, was 217 although the last consecutive reading was 241, showing a gradual decrease in hardness with depth was effected.

Insufficient hardness may be due to low percentage of carbon in the case, superficial decarburization, delay quenching, high drawing temperature, removal of too much stock in the grinding operation, etc.

Soft spots and insufficient hardness have been attributed lately to the presence of dissolved oxides in the steel. A material which hardens satisfactorily presents as carburized a 'normal' structure under the microscope while a steel which produces 'soft spots' has an 'abnormal' structure. The writer's experience has been that 'soft spots' have been a very infrequent cause of trouble and all cases which have occurred have been readily found due to some other factor than the steel.

Sudden cements have the tendency to push carbon in the steel much quicker than it can be diffused and produce high carbon cases particularly subject to enfoliation. It may be prevented by the use of cements which do not have such a violent action. Carburized parts must be heat treated so that they will give satisfactory service. The heat treatment must also be done economically or at the lowest cost consistent with good practice.

After being held the desired time at temperature, the grain of the case and core is large, due to the long soaking at high tem-

perature. If allowed to cool slowly, the excess carbide will form a network between the grains or separate in large masses. If quenched from a temperature which will harden the case, the carbide structure will not be changed and will form an easy path for fracture due to its intrinsic brittleness. Quenching in oil from the carburizing temperature where this excess carbide is in solution will precipitate it in extremely fine particles. It will not have time to separate between the grains. This quench also has a hardenening effect upon the core. The disadvantages are that it does not have any refining action upon the coarse grain left by the long heating, that the proper quenching temperature for the core is below the usual carburizing temperature and that large work is difficult to handle on account of the heat.

The pieces should be allowed to cool in the box and reheated to a temperature which will refine the core and also break up any undesirable structures of cementite. This is called a regenerative quench because it regenerates or restores the core.

The parts are then reheated to a lower temperature and are quenched to refine the case. This temperature is lower than the critical temperature of the core and the grain size produced in the core by the previous quench is not affected. This final quench may be in oil or water according to the type of steel. Some steels have the critical points of the case lowered by alloys to such an extent that they become hard when quenched in oil. Other steels are non-machineable after cooling in the carburizing box, due to the same phenomenon.

The stresses in some parts should be relieved by drawing in oil to about 375 degrees Fahr. This will not have any effect upon the hardness but will increase the strength, toughness and uniformity of the product. Chrome-vanadium steels require a drawing temperature about 25 degrees Fahr. higher than other steels to cause them to lose their file hardness.

The heat treatment and method of handling is varied in the usual manner according to the shape, size and previous history of the piece. The best results can undoubtedly be obtained by allowing the piece to cool in the box, reheating it to a high temperature to regenerate the structure of the core, reheating to a lower temperature to harden the case, and drawing to relieve the internal stresses set up in these operations. Costs, however,

regulate practice and are of course subject to the service requirements of the part. In many cases a single quench from the carburizing temperature is sufficient. An improved quality of product with lower costs can be obtained by a careful study of the material, heat treatment and service conditions.

TOOL ROOM TROUBLES

By A. H. Kingsbury

Abstract

The author of this paper has reviewed in considerable detail the various factors involved in the production of hardened tools. He discusses the necessity of a careful study of the problem at hand inasmuch as the improper selection of steel is the most frequent cause of tool room troubles.

Of the numerous factors involved in the production of cutting tools, the author specifically discusses the marking of various grades of steel, design, machining strains, heat treating, the proper hardening range, quenching speeds, drawing, soft spots and similar troubles, vanadium as an alloying element and grinding practice.

REFERENCE to trouble is generally distasteful to most of us. The word is, however, directly a stepping stone to experience and knowledge, especially when we recognize and admit the existence of trouble and in each occurrence make a careful analysis of its causes. The tool room personnel and equipment is of major importance in a plant inasmuch as the magnitude of the success or failure of the enterprise is to a considerable degree dependent upon the manner in which this department functions. The present day demand for economy in production to offset the shortage of labor and progressively ascending wages, has given the ways and means of doing things in the tool room, a significance greater than heretofore.

The gradual approach to perfection in our engineering practices, and the demand for greater and greater accuracy, have taxed to the utmost the originality and initiative of the tool designer and tool maker. Thus, the work of tool making demands more than a good mechanic and accurate workman. In the past these characteristics qualified a man for the trade, but at present the complex demands of modern pro-

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duction have raised it to the position of a fine art, in fact, an art upon which the ambitious and successful tool maker, designer, or treater may well look with considerable pride. Unfortunately all tool makers do not consider it in this light, and as a consequence fail to give their profession the careful study, the present situation demands. They fail to realize that constant evolution has, to a great extent, made the rule of thumb methods, instructions etc., of yesterday practically obsolete today, so that entirely new methods being in demand, the ambitious man will endeavor to gain that most necessary qualification for his work, namely, "originality." He may accomplish this by availing himself of some of the excellent and readily accessible sources of information in existence at the present time. The remarkable revolutionary period in engineering business, which started about twenty-five years ago is undoubtedly the direct result of publicity brought about by straightforward discussion.

As an example of this, let us consider the art of steel making. Not more than 20 years ago, the manufacture of tool and special steels was shrouded with a considerable degree of secrecy; each manufacturer had his own pet mixes, analyses and obscure methods of making his product. In fact his chief claim for consideration over his competitors was the carefully guarded obscurity of his entire process. The advent of the chemist and metallurgist along with the noteworthy progress made in their respective fields, has entirely dissipated the old order, and those subjects which previously were so jealously guarded, are openly discussed, and at the present time the steel maker bases his claim for consideration on the quality of his product as the result of research, knowledge, and care, which are the controlling factors in its manufacture. The writer wishes to emphasize his belief in the great benefit derived from these open discussions, for it seems to him that we must realize that the most abstract problems become simple in their solution when many minds are brought to bear on the subject. Thus, it naturally follows that the American Society for Steel Treating which was organized with the actuating purpose of discussing the complex problems confronting the worker in metals, is an organization of incalculable benefit to those who wish to avail themselves of not only a

technical but a highly practical education in the art of working and treating steel.

At times, unfortunately, the failure of tools is the fault of the steel and it is by the careful and thorough investigation of these failures, that the steel maker is progressively eliminating them. A personal observation points to the conclusion that in the instances where the blame rests on the steel, the majority of these cases are directly attributable to the "human equation."

Progress has been responsible for another and most encouraging change in the art of tool making. In the past, the trade was handed down from father to son and was really what might be termed a family affair. Like most things which are hereditary, the practice resulted in developments along narrow lines, and while it may have promoted a high degree of skill, it also resulted in an attitude both narrow and prejudiced. This condition has been subject to a radical change in that the tool maker at present is selected for his ability, regardless of what trade his ancestors followed. A man so developed is invariably open-minded and willing to discuss or listen to any subject which may be of benefit to him.

The Selection of the Steel

Possibly the most frequent cause of tool room troubles is primarily in the improper selection of the steel. In deciding this question to the best advantage, a careful consideration should be made of the work accomplished.

If the tool maker or designer does not have at least a working knowledge of the characteristics of the various tool and alloy steels available, or the proposition is one with which he is not thoroughly familiar, he can generally obtain the necessary information from the steel manufacturers, though in some instances the maker's experience will not allow him to state definitely just how the steel will perform under all conditions when it is in the finished tool. However, in making this choice the tool maker may find some assistance in the following questions:

1. What are the physical characteristics of the metal to be cut or otherwise worked by the tool? Is

it soft, hard, soft and tough, medium and tough, hard and tough, or will it have an abrasive action on the cutting edge of the tool?

2. Does the work planned necessitate an ordinary carbon, extra carbon, or alloy tool steel? Can initial hardness in the steel be sacrificed to gain toughness?

3. Does the class of work demand a deep hardening steel? Is there danger of the tool sinking and consequently cracking under pressure, when made from a shallow hardening steel?

4. How much size change is permissible in hardening?

5. At what speeds will the steel be required to work?

In answer to questions 1 and 2 for soft materials where toughness is not a factor, a hard steel should be used, and while most of this class of work can be satisfactorily accomplished by using a carbon steel, tungsten tool steels will generally give much longer service. For hard steel the same is true, but the difference between the length of service obtained by using one of the tungsten steels is much greater than where soft material is to be cut. For soft and tough cutting, a softer but tougher tool steel will show up to advantage though a harder steel may be used to a better advantage, if the drawing is sufficient to produce the maximum toughness obtainable with the necessary hardness. For hard and tough steels, alloy tools work to the best advantage, particularly the tungsten or chromium-tungsten steels, which develop a very hard close grain. This condition naturally enables them to resist wear and abrasion better than a steel which does not have this characteristic developed to the same degree. It is not intended to imply that good carbon steels will not be suitable for any or all of these classes of work, but the fact is emphasized that tungsten tool steels will work to advantage, and in the majority of cases give much longer service than those steels which do not contain this element. In aswer to question 3 it has been found that for most tools which have to withstand heavy pressures, such as dies, punches, etc., a deep hardening steel is recommended particularly for

those where the metal to be worked is dense in nature, or hard. A carbon steel, except in small sections will not harden deeply, so the use of an alloy steel is preferable. In addition to their deep hardening characteristics these alloy steels, either chromium, chrome-vanadium or chrome-tungsten, resist wearing action and abrasion. The oil-hardening nondeforming steels harden deeply and for many classes of punch and die work these steels are being used with a great degree of success. Another advantage gained by using this type of steel is that they do not change size in hardening. They do not attain, however, the intense hardness of some of the other alloy steels, and as a consequense can be used to better advantage on the softer classes of work.

The steels containing 2 to 7 per cent tungsten are capable of remarkable abrasion resisting qualities and their use is an economy for finishing tools on automatic machines for most classes of work. Their dense close grain will enable them to cut the hardest materials, but not at high speeds. The fact that a steel contains tungsten does not necessarily make it a high-speed steel, neither does it follow that the presence of this element will allow the tool to cut at much higher speeds than ordinary carbon steels, though the tungsten steels will last much longer on most of the materials at the same or slightly higher speeds and they will cut materials upon which carbon steels will not even start. Thus, the chief advantage of the tungsten over the carbon steels is longer service between grindings, a better finish due to their intense hardness, close grain, and their ability to cut materials which are too hard for carbon steels and at times impossible to cut with the standard high-speed steels. Due to their much wider hardening range, the hazard of loss by overheating in hardening is much reduced.

One frequently hears nearly all classes of tungsten steels referred to as semihigh-speed steels, but this terminology, the writer is convinced, is misleading. The fact that the so-called tungsten tool steels, such as those containing from 1 to 7 per cent tungsten, have their hardness breaking-down points but slightly higher than carbon steels and much below that of both the old self-hardening and modern high-

speed steels, would indicate the term "semihigh-speed" should be applied, if it is really necessary to apply it at all, to the almost obsolete self-hardening steel whose hardness breaking-down point is about 300 degrees higher than that for the carbon or tungsten steels and approximately 400 degrees below that of the modern high-speed steels. Therefore, if on using a carbon or tungsten steel at what might be thought to be sufficiently low speeds, the tool does not stand up and it is known that the proper conditions have been met in the treatment, do not jump at the conclusion that the tool has not been softened under the frictional heat of the chip simply because the edge does not show color or the softness cannot be felt with the file. Reduce either the speed or adopt a high-speed steel for the purpose and increase the speed, for as a rule, high-speed steels work to a disadvantage at carbon steel speeds.

From the foregoing it can be seen that the writer is particularly interested in tungsten steels, and he feels that an explanation as to his attitude is in order. Considerable time spent in research on the influence of tungsten in steel has indicated that it is a most fascinating field for investigation and has influenced him to form some theories and then search the literature for the purpose of confirming or contradicting them. While this search has to date been successful in uncovering a few technical articles by English and German authorities, there seems to be a dearth of papers either practical or technical on the subject by American authors. The careful perusal of those discussions that could be found on the subject of tungsten steels, with a personal investigation of some of their properties, have convinced the writer that this steel as a class, has been sadly neglected, and its thorough investigation in both a scientific and a practical manner by our modern metallurgists and tool makers will open up a very wide field of usefulness. Suffice it to say, that there is no doubt whatever, that these steels have latent possibilities which have been practically unexplored up to the present time, and careful and thorough research will, without a doubt, be repaid in concrete results. For this discussion the steels referred to as "tungsten steels" are those which contain tungsten in excess of 1 per cent and do not come in the high-speed or "self hardening" steel classes.

Vanadium As An Alloying Element

Vanadium as an alloying element is very active in changing the properties of steel. In fact, it is so active that its addition to the extent of even 0.15 per cent makes the steel to which it is added an alloy steel, while any of the other alloying metals have to be present in appreciably greater quantities to place the steel in the alloy class. The addition of vanadium in correct proportions to a carbon steel, adds several valuable properties, such an increased hardness and toughness, both of which augment to a great extent the life of the tool. It also adds several other properties to steels which however, are of no direct bearing on the subject so will not be discussed.

The acknowledged superiority of the vanadium-carbon steels over the straight carbon steels in durability is no doubt due largely to the fact that vanadium resists the formation of lamellar pearlite and in hyper-eutectoid steels massive cementite, thus acting to give the annealed steel a finely spheroidized structure which is the ideal structure for tools. In addition to increased hardness and toughness, vanadium also acts like chromium in increasing the depth of hardness.

Proper Hardening Range

Another condition which has frequently caused trouble is heating a carbon steel beyond the proper hardening range to gain a greater depth of hardness, for while this practice will result in a harder core, the hard surface is correspondingly weakened by coarsening the grain, and the service from the punch or die, is thereby sacrificed. When it is found necessary to prevent sinking because of a soft core, a deep hardening steel such as a chromium or chrome-nickel, nondeforming or high-speed, should be used. In fact, when any serious doubt exists as to just what steel to use it is generally a safe bet to try high-speed steel which, with our present knowledge of the elasticity of the treatment of this type, makes it suitable for almost any kind of tool.

For a precision tool the nondeforming oil-hardening types of steel are obviously the best. The size change, however, in either a carbon, tungsten or chromium steel can be greatly reduced by roughing it out, oil hardening it at from 50 to 75

degrees Fahr., above the temperature at which it would ordinarily be quenched, and either draw or anneal it just sufficiently to allow it to be finished up, then apply the regular treatment. This makeshift should never be resorted to unless a nonchangeable steel is not available or suitable for the work.

Marking Grades of Steel

As all tool rooms use more than one kind of steel, a method of keeping the various classes of steel separated must be adopted. The system of symbolizing the various kinds of steels should be such that the short and smallest pieces can be easily identified. Different colored paints and numbers or letters stamped on the bars or pieces are the best means of preventing mixups. If when the bar of steel is received it is immediately painted with a stripe the length of the bar, stamped, lettered or painted, a distinctive number, letter or color on each end, it can be easily identified at any time. Failure to do this may result in the loss of some very expensive tools.

Design

The design of the tool is one of the most important features, as it relates to the cutting angles and many other elements which are large factors in the ultimate results obtained. The importance of proper lip angles is so well known that it seems unnecessary at this time to dwell upon this essential feature. The tool designer should consult with the hardener and in any event should understand the fundamental principles of hardening. Sharp corners, adjacent thick and thin sections are potential causes of cracks and spa'ling and should be avoided when possible. If not possible and the tool is to be an expensive one, use an oil hardening or high-speed steel.

Some tools, regardless of how carefully they are treated, will warp and this point is where the good hardener can be of assistance to the designer, for he can advise him where the warpage is likely to occur and thus provision can be made for grinding. If the tool is such that it cannot be ground subsequent to hardening, the safest procedure is to use a nondeforming or nonchangeable oil-hardening tool steel.

All hot rolled or hammered steels are likely to have a

more or less decarburized surface, so it is poor economy to buy the steel too close to the finished size, as sufficient material should always be allowed to insure the complete removal of the decarburized surface.

In designing punches and dies, the proper clearance is of basic importance. It is difficult to establish hard and fast rules to cover this point due to the action of the various metals which may be fabricated by the tool. However, a safe rule which can generally be followed is to allow clearance equal to about 1/6th of the thickness of the metal to be punched. For hard metals this ratio can be reduced to as much as 1/12th. When punches break; a good practice is always to start with the investigation of the clearance, providing that the fracture of the tool does not indicate anything irregular in its physical properties.

Heat Treating

The subject of this paper would indeed be but poorly dealt with if due consideration were not given that most essential adjunct to the tool room, namely the heat treating department, for it is here that a majority of tool room troubles have their origin. In considering this phase of the subject, the writer will necessarily have to present it in a general and not a detailed manner, for were it to be dealt with in detail, and in justifiable way, this meeting would have to assume the proportions of a convention.

The use of a pyrometer is strongly recommended as it is of valuable assistance in duplicating results. An instrument, however, which does not have the necessary attention and is not checked for accuracy from time to time is obviously of negative value and the source of trouble. Fortunately the present product of the pyrometer makers is as near fool proof as they can possibly make it, but they are not perpetual motion machines and consequently need a little of the human touch now and then, to keep them in condition.

Where it is possible, an instrument should be kept for checking purposes, but where this is not practical, service can be had at any time from the maker, for a very nominal charge. The instrument is of assistance to, but cannot take the place of

the intelligent hardener and therefore its introduction should not lead to the conclusion that hardening troubles are at an end. It will measure the degree of heat in the particular section of the furnace where the hot junction is located, but sometimes furnaces do not heat uniformly. Consequently, unless the furnace heats uniformly and the operator knows how to use the instrument, either the steel, the pyrometer, or both, are placed in a very disadvantageous position. The pyrometer helps to regulate the "human element" but neither it nor any other instrument designed to date can eliminate the hardener, who should have just as much if not more, skill and judgment than his predecessors of years gone by when steel was hardened by the eye, and the hardener was considered a specialist.

In addition to the pyrometer and the hardener, the proper furnaces and hardening room equipment are necessary if trouble is to be avoided. As details of the equipment have to be suited to the peculiar requirements of the individual shop it is impossible to consider them in any more than a fundamental way in this discussion. The furnaces should be so designed that they will be of ample size for the work, and capable of maintaining a uniform temperature throughout. The fuel supply, the valves, drafts, etc. should be such that the atmosphere of the furnace can be kept either neutral or reducing at all times. If precision and delicate tools are to be treated, one or more preheating furnaces are of great assistance.

A brine of water tank or both and a suitable oil quenching system of sufficient size are necessary. The water and brine cooling tanks should be so designed that the temperature of the quench can be kept below 70 degrees Fahr. A good thin quenching oil is easily obtainable. Either furnaces, oil baths or some other means should be provided for drawing and as a necessary adjunct to them a suitable means for accurately determining their temperature, though tempering by color, if it is thoroughly understood will be suitable for some classes of work. It must be remembered however that temper colors do not appear below 420 degrees Fahr. and this is too high for many tools; thus to get accurate results, a furnace or bath with a temperature indicator is good and in the long run, an economical investment.

Cracking, spalling and warping are the direct results of

strain. Nonuniform heating and cooling conditions are by far the causes of the greatest majority of these troubles. Thus by a careful and thoughtful consideration of the conditions from which strains originate, many of the troubles incident to hardening can be eliminated. It is admitted that the design to which some tools have to be made will invariably produce warping. A proper attention to the heating and quenching as well as to the selection of the steel can reduce this condition to a point where it is almost negligible, and if necessary, the tools can be straightened at the drawing temperature.

All steel in the first operation (hardening) should be treated in such a manner as to give it the greatest possible hardness with the greatest refinement of the grain, and the proper hardness for the finished tool should be regulated by the degree to which it is drawn. In its initial hardened condition, the steel is under a tremendous strain particularly, if its design makes necessary adjacent thick and thin sections, sharp corners, etc. It is therefore obvious that this tension or strain should be relieved as soon as the quench has proceeded to the degree where maximum hardness is obtained. The exact point in the quench where this condition is reached is difficult if indeed possible to determine, but best practice and experience indicate that it is somewhat higher than the temperature of the quenching both, particularly if this be water or brine. If the quench is in oil, it should be used hot, generally from 80 to 150 degrees Fahr., for oil hardening steels, and as hot as possible for high-speed steels, so the careful attention to relieving strains at once, while it is not as essential as for the water or brine hardening steels, is good practice. A procedure which seems to be productive of good results is to continue the quench in water or brine, until the hand can just touch the piece and then finish cooling in either hot oil or draw the tool. This practice also assists in preventing warpage. On the other hand care should be taken not to remove the piece from the bath when it is too hot, for internal expansion from the interior which, to a certain point is bound to be hotter than the outside will cause cracking, spalling or warping. Allow the quench to proceed to the point where all vibrations have apparently ceased, then place the tips of the fingers down in the bath and on the piece, and at the point where it can just be touched

but not held without discomfort, it should be removed and either drawn or otherwise "let down" as described.

Machining Strains

Another cause of cracking or warping is machining strains and while this condition is not very common, it is one which should be recognized as very aggravating, for it is likely to occur in the most expensive tool or where considerable amount of machining has been done. As an added insurance against trouble from this source, certain tools, should have the machining strains properly relieved by heating and cooling before hardening is attempted.

Cracking and failure in service are generally the inevitable results of over-heating or under-heating by hardening too close to the critical point. With our present facilities and sources of information the former is hardly excusable while the latter can be avoided by the proper care and attention on the part of the hardener. Failures from over-heating are readily discovered by observing the grain size in the fracture, while those from a quench too close to the critical are more difficult of detection by the naked eye, are readily found by the microscope. A piece which is quenched too close to its critical, while the fracture may appear normal to the unaided eye, is weak and its hardness breaking-down point is lowered. As an illustration of this condition; sometime ago a failure of a tungsten steel chaser die was reported; investigation developed the fact that on hardening from 1480 degrees Fahr. the dies passed the required file and scleroscope tests but on drawing at 375 degrees Fahr. (25 degrees below the established standard) the tools developed softness, and on test the teeth broke out. From the claimants point of view there was something radically wrong with the steel, as their treatment so far as they knew, was an established standard with them over a long period of time and the trouble had never occurred before. The answer to the problem was in the fact that they had not checked their pyrometers, and when this was done, it was developed that for some unaccountable reason they were registering from 20 to 40 degrees Fahr., low. When this was corrected the trouble was overcome, and the drawing could be done at 400 degrees Fahr., as before.

During the course of investigating, it was also demons-

trated, that the steel had a hardening range of about 150 degrees Fahr., and to avoid a reoccurrance of the trouble, the hardening temperature was raised to 1525 degrees Fahr. Similar troubles namely, weakness and loss of hardness below the normal breaking-down temperature will manifest themselves in almost any steel, even high-speed steels. The danger point in these steels apparently is located somewhere between 2000 and 2200 degrees Fahr While we are informed that the transformation points for high-speed steels are considerably below this range, there is very substantial evidence that a most important change occurs in the modern standard steels, between 2000 and 2200 degrees Fahr.

While on the subject of high-speed steels, it is necessary to mention the fact that a considerable proportion of troubles are caused by the hardener's ignoring or rather failing to recognize the fact that high-speed steels are sensitive to the time element, as they are subject to rapid grain growth at temperatures in excess of about 2000 degrees Fahr., or during the superheat. For this reason the superheat should be as rapid as possible to be consistant with uniformity. Maintaining the superheat from 50 to 75 degrees Fahr., or even higher, over the intended quenching temperature, and quenching when a uniform sweat has appeared on the cutting surfaces, will greatly assist in reducing the time element.

The question is frequently asked, how can one identify the proper quenching temperature for high-speed steels? This is difficult to answer, as differences in analysis affects this point However, for the standard 16 to 18 per cent tungsten steels, a quench from 2300 to 2350 degrees Fahr., (tool temperature) seems to be the best, while for the lower tungsten or special high-speed steels, temperatures somewhat lower should be used. These lower tungsten steels are not at present in general use, so it seems unnecessary to dwell upon this feature further. Should anyone be interested in them, the writer as far as experience enables him will be glad to answer questions regarding them. The fact remains that many plants have not the pyrometer equipment for measuring high temperatures, at which high-speed steels have to be quenched, consequently the bare fact that 2300 to 2350 degrees Fahr. is productive of best results means little or nothing to them. The following hints will, it is hoped, assist in finding the proper

temperature. Prepare a few sample discs or pieces of the steel as nearly uniform in shape and size, as possible. Preheat these uniformly to a temperature of anywhere from 1500 degrees to 1800 degrees Fahr. Be sure that a neutral or nonoxidizing atmosphere exists in the superheat and quench from various temperatures as shown by the varying intensity of sweat from where it first appears up to the blistering point. Fracture these pieces and note between which points the maximum refinement of fracture is obtained. Then draw the pieces thoroughly to 1100 degrees Fahr. and test with a sharp file.* Those pieces which are soft indicate too low a quench and by this elimination the ones which are hard and still show the finest fracture are those which have been quenched inside the correct range for the steel.

Most high-speed steels are greatly weakened if they are blistered, and this condition must be avoided, if maximum results are to be obtained. A properly hardened high-speed steel tool should never show scale holes, rough or so called 'alligator skin' surfaces.

For very heavy sections or complicated tools, and those where loss in size must not occur, heating in these stages is most desirable, though not absolutely necessary. First a very thorough preheat between 1400 to 1500 degrees Fahr. or below the scaling point, second an intermediate heat between 1700 to 1800 degrees Fahr. from which the tool should be transferred to the final or superheat just as soon as it has attained the heat of the intermediate furnace, and before scale has had a chance to form. It should always be borne in mind, that excessive scaling is likely to result in blisters, soft surface and is certain to result in loss of size.

The essential precautions to observe when treating high-speed steel tools are thorough preheating, prevention of scaling as much as possible by a proper manipulation of the furnaces, a quick high superheat, hot quenching medium and a thorough drawing as soon as possible after hardening.

It frequently happens that a hardener, who has not been accustomed to handling them runs into trouble when he is first introduced to a chromium, chromium-tungsten or tungsten tool steel, unless he knows something regarding the nature of these

*If test for hardness is made on the black surface it will be misleading. Either grind spot or test on a fresh fracture.

alloys. The introduction of either one or both of these elements raises the critical points and consequently the quenching temperature, and increases the density of the metal, and therefore the tool made from these steels must necessarily have more time in the fire to insure uniformity throughout. While information is readily available just how to treat these alloy steels their nature can be better understood by the hardener, if he will follow the practice of personally experimenting on some small test pieces to firmly fix in his mind the temperature range and other conditions through which maximum hardness and grain refinement takes place. This is far more economical than experimenting on expensive tools.

Critical Quenching Speed

Every different variety of steel has what might be termed its 'critical quenching speed,' that is the speed at which it is necessary to reduce its temperature in cooling through the Ar point and which will result in the maximum degree of hardness. Thus, while it is most desirable to quench carbon and some of the alloy steels as rapidly as possible to hold the carbide or carbides in solid solution, there are certain steels where the addition of such elements as chromium, manganese, tungsten, vanadium, either singly or in combination acts as a brake in preventing this transformation from taking place, in fact there are some of these steels among the chromium steels, those containing 6 per cent chromium, high chromium-tungsten such as air hardening, or high-speed steels, certain combinations of chrome-nickel and certain high manganese steels where a comparatively slow cooling from temperatures above those at which carbide solution takes place (critical point), will result in the lowering of the conversion point on cooling to such an extent as to give a high degree of hardness. As none of the alloy steels will harden to any great extent unless carbon is present in the steel, the obvious conclusion is reached that this so called, 'lowering' action is due to the effect of the combined alloy tending to hold in solid solution, the dissolved carbides. Though it may in some cases be difficult, practically all these alloys can be softened by annealing. It is also known that most of these alloys can be suitably hardened in oil, the quenching speed of which is slower than water or brine, and practically all of them will crack when quenched in water or brine, also

some when certain kinds of oil are used for it is a fairly well known fact, that all oils do not quench with the same speed.

Quenching Speed

The question of quenching speed is brought forward because of the theory which the writer is convinced is erroneous, and which seems to have some degree of popularity in many places namely that, 'the more rapid any steel, regardless of its composition, can be quenched the greater will be the resulting hardness.' Thus one sometimes finds steels which should be quenched in oil, being hardened in either very thin oil, water or brine in attempting to increase the hardness. The evidence seems to be very conclusive that inasmuch as the critical quenching speed is influenced by the composition of the steel, it is necessary to quench it in a medium which will cool it with a velocity either equal to or slightly in excess of this critical quenching speed, and when this condition has been satisfied, any increase in the velocity of quench by changing the quenching medium will not result in any greater degree of hardness, but more than likely in contraction cracks and in any event, weakness. Thus it follows that oil or self hardening steels must not be quenched in water, or any other medium which will increase the cooling velocity beyond the danger point. If consistent cracking is experienced, this feature should be thoroughly investigated as it is known that different oils will vary in the speed with which they quench, and water sometimes finds its way into the oil tank. The writer has purposely concentrated on the effect of quenching speed as he is convinced from his own experience and that of others, that troubles from this source are of frequent occurrence.

Soft Spots and Similar Troubles

Soft surfaces, soft spots, and some other undesirable results such as size change, generally are due to the practice of improper heating. It must be borne in mind, that scale is an oxide, and oxygen has affinity for carbon, when the temperature is sufficiently elevated. Thus, a tool which is badly scaled by either, an oxidizing furnace atmosphere or excessive soaking, generally develops

a more or less decarburized and consequently soft surface. Though the soaking at scaling heats may not be sufficiently prolonged to result in actual decarburization there is danger of sections of scale adhering to the surface, and acting as insulators in the quench, resulting in soft spots underneath. Cold tongs, hooks, etc., are also potent causes of soft spots and while their use is generally necessary a little judgment and discretion will indicate a portion of the tool where extreme hardness is not of paramount importance and where it can be held with the tongs or hook with impunity. Do not allow the tool to remain stationary in the quench thus giving the water time to form steam pockets which will not only insulate that portion of the tool where they are formed, but will in many instances result in fracture. The piece should be kept in motion; where there are deep depressions to be hardened, a forced stream should be directed on or in these depressions. If a rehardening is necessary it should be proceeded by a thorough anneal to remove the effects of previous treatment. Lack of attention to this precaution is likely to result in failure if not in total loss of the tool.

The prevention of excessive size change is best accomplished by the use of a nondeforming steel, where it will meet the working conditions. As most steels are subject to an increase in specific gravity, by hardening they naturally shrink. Where shrinkage must be held to the lowest possible degree and a nondeforming steel is not used, the tool should be thoroughly preheated between 1250 to 1350 degrees Fahr. and from this point as rapidly as possible to the desired quenching temperature. By a proper regulation of both furnaces this can be accomplished uniformly and without considerable loss of size or other undesirable condition from scaling.

Grinding which is such as to raise the temperature above the breaking-down point will naturally result in skin softness and frequently in cracks. This may be remedied by a free cutting wheel, light cuts and at proper speeds, which good practice has shown should vary according to whether the steel is carbon or high-speed. One abrasive wheel maker, recommends for the best results, a somewhat coarser and softer wheel, and if possible slightly decreased speeds for high-speed and other very hard alloy steels, than are generally used for carbon or other similar steels.

Drawing

Even if a tool has reached this stage in its development where it is to be finish-ground without showing any defect, it does not necessarily follow that it will work to the best advantage, if the drawing has not been correctly accomplished for the class of work which the tool is to come in contact. As indicated before, the operation of drawing, has a major influence on the final results obtained. No hard and fast rule can be laid down for governing this operation for all varieties of work, as this can only be determined by experience and the careful observation of the way in which the tool fails. Suffice it to say that many a tool and many a good tool steel has been discarded for a certain purpose as being too soft, when exactly the reverse has been the case. A rounded or turned over cutting edge does not always signify that the tool is soft, because the tools often attain this condition when too hard, by minute crumbling at the edge, due to the rubbing action of the work, giving them the appearance of being too soft. When a tool fails and it is known that the hardening conditions have been correct, raising the drawing temperature in many cases will remedy the trouble.

Conclusion

Finally, to sum up the text of this paper, it has been shown that tool room troubles can be greatly reduced if not entirely eliminated by:

1. The proper selection of the steel.
2. The proper design of the tool avoiding sharp corners, and adjacent thick and thin sections as far as possible.
3. Co-operation between hardener and designer.
4. Good, though not necessarily expensive, hardening room equipment.
5 Uniform heating and quenching.
6. Drawing to relieve strains as soon as possible after quenching.
7. Knowing the hardening range of the steel and keeping well within it.
8. Not attempting to increase the hardness of a self or

oil-hardening steel by using a cooling medium of greater velocity than that in which it is designed to be cooled.

9. Using preheats wherever possible.

10. Where a large amount of machine work has been done, or warping is likely, annealing before hardening, to relieve machining strains, and annealing if rehardening is necessary.

11. Avoid scaling which will result in loss of size, appearance of soft spots, etc.

12. Proper grinding practice.

13. Drawing to the degree which will produce the toughness necessary to best accomplish the work for which the tool is designed.

THE ANNEALING OF SHEET STEEL

(Continued from Page 139)

stock must be reannealed after cold rolling to remove the strains of cold working. This second annealing operation is very important with light gage sheets, on account of the high phosphorus content. While it might be again said that the correct temperature would be 1620 degrees Fahr., these sheets, now with a high polished surface will stock or weld together much more easily, and since this added expense has been put upon them, loss from stickers will amount to considerably more in money. Experiments showed that on this class of material a temperature of over 1150 degrees Fahr. would cause stickers, and that 1200 degrees Fahr. or over made them impossible to separate. Therefore, the second annealing is very light and it is impossible to remove all strains unless they were annealed in very thin packs, where their weight would not hold them close enough to stick. The roof temperature on cold rolled material does not run over 1400 degrees Fahr. and the firing time about 8 hours.

Blue Annealing

Heavy gage sheets (sheet mill material) are ordinarily spoken of as blue or box annealed. In this sense, blue annealed means the open annealing of a sheet in an open furnace, the sheet always having considerable scale on it. Blue annealing by the box method is quite a different thing, and as a large tonnage of light gage stock is marketed this way the annealing of it is important. The purpose of blue annealing is to cover the surface of the sheets with a rust-resisting coating of oxide, which being in the form of Fe_3O_4 will vary from a light blue to a black. The material may be made as stove pipe, elbow, or high polished stock, with numerous grade between.

Most of the methods for blueing take place during the annealing operations and are so closely related that a study of one must include a study of the other. The author has experimented with some twenty-one methods of obtaining a blued sheet by air, gas, steam and chemicals. The results, however, of these tests are not incorporated in this paper. These few words on blueing

are merely to bring to the readers attention the importance of annealing in the sheet steel industry.

Summary

In summing up this paper the contents may be briefly classified into the following 14 points.

1. The most common type of annealing equipment is the box type furnace and annealing boxes.

2. The continuous box type furnace gives better heat control.

3. The continuous muffle type furnace should show a considerable saving in fuel due to the fact that there would be no heat wasted in heating covers and bottoms.

4. Pyrometers on roof work require rare metal couples and the method of measuring temperature within the box is expensive and unsatisfactory.

5. Softness of the sheet does not necessarily mean good stamping quality.

6. A dirty surface will cause a well annealed sheet to break in stamping.

7. Steel should be as low as possible in sulphur and phosphorus with carbon and manganese within reasonable limits.

8. Grain growth must be prohibited even at the expense of incomplete removal of rolling strains.

9. Sticking is the result of a high annealing temperature and frequently is accompanied by grain growth.

10. The heat distribution in the cannon ball furnace is good, but charging of the boxes is difficult.

11. The bench type furnace, while easy to charge, exhibits poor heat distribution.

12. Stoker-fired furnaces are as economical as hand-fired furnaces.

13. Bringing up the temperature as rapidly as possible will help to clear the sheets. The heat absorption of steel is a definite quantity with time and temperature the main factors.

A high furnace temperature only burns up the furnace and covers.

14. Deoxidizing and blueing are operations carried out on the steels while in a heated condition.

NOTES FROM THE BUREAU OF STANDARDS

The Form of Oxygen in Steel Determined by Vacuum Fusion Analysis

PREVIOUS tests have indicated that oxygen existing in iron or steel as iron oxide or silica is completely determined by the vacuum fusion method of analysis for gases in metals. Additional tests have been made with oxides of manganese and aluminum, the results showing a recovery of over 90 per cent of the oxygen in either of these oxides, the oxides used in such tests being in comparatively coarse particles.

It has been shown, both in these tests and by previous investigators, that the reduction of such oxides by carbon is more complete the finer the oxide. It is, therefore, believed that such oxides contained in steels as very fine inclusions are completely reduced in the vacuum fusion method of analysis.

Nick-Bend Tests of Wrought Iron

Previous work on this subject by the Bureau has shown that the character of the crystalline areas which are often obtained when wrought iron bars are fractured by the nick-bend test is determined largely by the relative size and distribution of the slag threads. In general the smaller the slag threads and the more uniformly they are distributed, the greater is the tendency for crystalline areas to occur.

In order to confirm this tentative conclusion, considerable attention has been given to the nick-bend test of open-hearth iron. It was noticed that the full-sized bars broken in the regular manner of the nick-bend test invariably gave crystalline fractures. The observations previously made on the difference in the nature of the crystalline break on the tension and compression sides of the bar were also confirmed. On the other hand, a large number of the small impact specimens cut from such bars and tested by the Izod and Charpy methods gave silky fractures. Evidently, the nick-bend test should not be considered merely as an impact test of the Izod and Charpy types on a large scale.

By annealing impact specimens of the open-hearth iron at high temperatures up to and including 1150 degrees Cent., which renders the grain size larger and more uniform, the fractures obtained in the impact test were very similar to those in the simple nick-bend test of the the untreated iron. However, some of the bars annealed at high temperatures still showed a silky fracture after the Charpy impact test. It appears probable, therefore, that the resistance of the iron to

shock is not determined simply and wholly by the grain size; but that other features, such as the form of the grain, particularly the character of the junction between neighboring grains, may affect the results. Microscopic examinations of fractured specimens are being made to throw light upon this.

Crystalline Form of Electrodeposited Metals

A paper entitled "Notes on the Crystalline Form of Electrodeposited Metals" has been prepared by members of the Bureau's staff for presentation at the fall meeting of the American Electrochemical Society. The purpose of this paper is to present a simple theory on the mechanism of electrodeposition and a classification of structures which the Bureau believes will be helpful in further studies in this field.

The Quenching of Oil-Water Emulsions on Gage Steel

Considerable time was devoted during the month of June to a study of the characteristic behavior of an oil-water emulsion (a mixture used commercially to some extent) as a quenching medium in the heat treatment of steels.

It was found necessary to stir the mixture with high pressure air to obtain a homogeneous emulsion in which condition it was very stiff and cooled the specimen much more slowly in the upper temperature range than oil. It had the peculiar property of cooling slowly half way and then very rapidly, the time to cool to one-tenth of the temperature range being about the same as for oil. This unique property is evidently due to entrapped air and should be studied further. When completely emulsified, it was not possible to harden standard cylinders of 1.4 per cent chrome steel though they could be hardened if the mixture was not thoroughly emulsified.

Additional Foundry Equipment

Up to the present time, nearly all the work of the Bureau's foundry has been limited to the preparation of nonferrous alloys. Recently the Bureau has purchased a small cupola to be used for investigational purposes in connection with the ferrous alloys and also to provide metal for castings used by the Bureau and other branches of the government. During the month of June the construction of a charging platform and foundations for the cupola were completed. The installation and lining of the cupola are now in progress and the equipment will soon be ready for service.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 88. What are the flash and fire points of the principal vegetable, animal and mineral oils?

QUESTION NO. 89. What are the melting points of the principal chemical elements?

QUESTION NO. 90. Please give the temperatures and corresponding temper colors used in the drawing of carbon steel.

QUESTION NO. 91. Please state the temperatures and corresponding colors used in hardening carbon steel.

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel?

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

QUESTION NO. 86. Can ingotism in steel be removed by subsequent rolling or forging?

ANSWER—By M. H. Medwedeff, metallurgist and chemist, Wyoming Shovel Works, Wyoming, Pa.,

Ingotism in steel is not such a rare phenomenon as it is commonly supposed, particularly in alloy steels made in large open-hearth furnaces and poured into large moulds. But the bad effects of ingotism, i. e., the inherent weakness due to an excessively large grain, are easily overcome by subsequent rolling or forging at proper temperatures.

Ingotism in steel is the phenomenon of an excessively large grain in the cooled ingot. This occurs whenever the solidification range is very wide, i. e., when the pouring temperature is too high, or in general whenever the passage through the solidification has been too slow.

In rolling at proper temperatures, above the critical range, the mechanical work crushes the large crystals which are immediately reformed into smaller crystals. The final size of the crystals will depend upon the finishing temperatures. If the work was stopped when the steel was slightly above the critical range the steel would have a fine grain and the physical properties of the erstwhile brittle steel would be very good. Careful forging will also remove the effects of ingotism.

QUESTION NO. 87. What is the reason for the distortion of gears made of S. A. E. 3120 steel after carburizing according to recommended heat treating practice of the S. A. E.?

ANSWER. By James Sorenson, metallurgical engineer, Four Wheel Drive Auto Co., Clintonville, Wis.

One of the primary causes for gears made from S. A. E. 3120 steel distorting after carburizing is due to the gear blanks

not being thoroughly annealed before carburizing, fluctuation of temperature during the carburizing operation or the use of too drastic a quenching medium in the hardening operation, may also be the cause.

The writer has handled a great many tons of gears made from S. A. E. 3120 steel in the following manner and has always had very good results, both as to uniformity in hardness and structure and a minimum amount of distortion.

The treatment is as follows: After machining of gear blanks anneal at a temperature of 1550 degrees Fahr. and cool in the furnace, finish machine and carburize at 1650 degrees Fahr. Cool in boxes. Reheat to 1575 degrees Fahr. and quench in oil. Reheat to 1450 degrees Fahr. and quench in oil. Draw temper according to the desired hardness of the case.

ANSWER—By M. H. Medwedeff, metallurgist and chemist, Wyoming Shovel Works, Wyoming, Pa.

Gears will distort during the carburizing process due to various causes. Sometimes excessive distortion will result from improper packing of the gear in the carburizing boxes, i. e., uneven distribution of weight of gear surface. Distortion will also result if the carburizing boxes are unevenly heated, due in turn to faulty furnace operation. The writer has often observed portions of carburizing boxes red hot while other portions are almost black.

Gears should be packed in such a manner that the weight is evenly distributed. Another very common source of distortion is when gear blanks have not been properly annealed and the large forging strains not removed.

To minimize distortion in gears the furnace charge should be brought up slowly to the desired carburizing temperature, and the burners manipulated in such a manner that the furnace chamber is evenly heated. This is very simple if the operators are trained in proper adjustment of burners. It is really remarkable how little attention is paid to this point. It is also important to allow the gears to cool in the boxes until black.

Uneven heating and faulty distribution of weight of gear in quenching will also cause distortion.

In the July issue of TRANSACTIONS, Question No. 76 was answered by B. F. Weston of the Jones & Laughlin Steel Corporation. It was stated that Mr. Weston was located at the S. S. Works, Beaver Falls, Pa. This statement should have been South Side Works, Pittsburgh, Pa.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective

NEW MEMBERS

ALLISON, A. R., (Jr-6), 58 Chestnut St., Lewistown, Pa.

BARTLETT, C. F., (M-4), Box 350 Redford, Mich.
BECK, F. A., (M-6), 4636 E. Thompson St., Philadelphia, Pa.
BENDIXON, H. H., (Jr-7), c/o Bettendorf Co., Bettendorf, Iowa.
BOLTON, H. L., (M-6), Beacon Oil Co., Everett, Mass.
BRUNNER, E. H., (M-6), 621 Fourth Ave., Bethlehem, Pa.

CAMPBELL, L. A., (M-3), 1041 W. Forty-eighth St., Los Angeles, Cal.
CANDLIN, WALTER, (A-5), 5034 Tamson St., Philadelphia, Pa.
CANN & SAUL STEEL CO., (S-6), 516 Commerce St., Philadelphia, Pa.
CARLSON, J. V., (M-5), Union Special Machine Co., Chicago, Ill.
CASLIN, JAMES, (M-6), 5923 Romania Place, St. Louis, Mo.
CLAYPOOL, W. L., (Jr-7), Bettendorf Co., Bettendorf, Iowa.
CLEMENT, H. L., (M-5), Union Special Machine Co., Chicago, Ill.

DEANE, H. A., (Jr-7), 1183 Twenty-fifth St., Moline, Ill.
DENNY, A. B., (M-3), Llewelyn Works, Torrance, Cal.

ELLIS, O. W., (M-6), Dept. of Met., University of Toronto, Toronto, Ontario, Canada.

FENTRESS, G. E., (M-7), 2525 Thirty-seventh St., Los Angeles, Cal.
FRAUENTHAL, A. H., (M-4), 998 Parkwood Drive, Cleveland, O.
FUREY, CORNELIUS A., (M-5), 2620 S. Sixteenth St., Philadelphia, Pa.

GILCH, JOHN A., (M-6), 305 Van Vranken Ave., Schenectady, N. Y.
GOODENOW FURNACE CO., F. J., (S-4), 2153 Warren Ave. W., Detroit, Mich.

HOTCHKISS, R. M., (M-6), 263 Park St., New Haven, Conn.
HYBINETTE, V., (A-6), Hotel Dupont, Wilmington, Del.

KINNEY, L. W., (M-6), 18100 Cornwall Rd., N. E., Cleveland, O.

LA VAN, MONT, (M-6), Mechanics Machine Co., Rockford, Ill.
LEWIS, H. R. Jr., (M-6), Ohio Seamless Tube Co., Shelby, Ill.
LIGHTFOOT, H. A., (M-5), 1633 Dyre St., Frankford, Philadelphia, Pa.
LOVELL, A. C., (M-7), Fabric Tool Protector Co., South Bend, Ind.

MAXFIELD, T. C., (A-6), E. F. Houghton & Co., New York City.

NICKLE, H. D., (M-5), 532 Beacon St., Boston, Mass.

PEARNE, F. Y., (M-3), 209 E. Ave. 55, Los Angeles, Cal.
PIRK, G., (Jr-7), General Electric Co., Schenectady, N. Y.

RADFORD, V., (M-7), National Malleable Castings Co., Sharon, Pa.
REEVES MFG. CO., (S-6), Milford, Conn.
ROSS, J. G., (M-7), 1036 S. Main St., Waterbury, Conn.

SOVERHILL, H. A., (M-5), 1120 Thirteenth St., Moline, Ill.
SZEKELY CO., C. O., (S-7), Sixth Ave., Moline, Ill.

TREANOR, J. D., (Jr-6), 416 Eighteenth Ave., Moline, Ill.

VIERIECK, A. L., (M-5), 224 S. Pine St., Davenport, Ia.

WALEN, E. A., (M-6), Bellis Heat Treating Co., New Haven, Conn.
WARD'S SONS CO., EDGAR T., (S-6), Sixteenth St., and Indiana Ave., Philadelphia, Pa.
WEBSTER, G. W., (Jr-7), 583 Central Ave., New Haven, Conn.
WOOD, LEON G. S., (Jr-6), Saco-Lowell Shops, Lowell, Mass.

CHANGES OF ADDRESS

ADAMS, H. R., from 816 W. Lake Street, to 1302 W. Washington Blvd., Chicago, Ill.

ADAMS, J. O., from 930 Church St., to E. C. Atkins Co., Indianapolis, Ind.

BODINE, FRANK, from 2303-14th Ave., to 1312 Seventh St., Rockford, Ill.

BURKE, THEODORE, from Isaac G. Johnson Co., Spuyten Duyvil, N. Y., to Otis Elevator Co., Buffalo, N. Y.

CHABOT, J. M. T., from 23 Silver St., Waterville, Maine, to 115 Court St., Charleston, W. Va.

CINIOTTI, G. E., from 726 N. Beatty St., Pittsburgh, Pa., to Vanadium Alloys Steel Co., Springfield, Mass.

COLLINS, ARTHUR L., from 5616 Crowson St., Germantown, Pa., to Horace T. Potts & Co., Philadelphia, Pa.

CONRADI, L. C., from R. F. D. No. 1, to 143 Jackson Ave., Plainfield, N. J.

CORNISH, F., from 3 Greenwood Ave., to 288 Vernon St., Blue Island, Ill.

CRAMP, ARTHUR L., from Imperial Drop Forge Co., to Route "C," Box 393, Indianapolis, Ind.

DAY, WM. E. Jr., from 311 Magnolia St., to International Motor Co., New Brunswick, N. J.

ESAU, G. W., from 6739 Cornell Ave., to E. F. Houghton & Co., Chicago, Ill.

FISCHBECK, H. J., from 137 Twenty-second St., Irvington, N. J., to Pratt & Whitney Co., Hartford, Conn.

FREDERICK, J. B., from Poole Hotel to Barber Colman Co., Rockford, Ill.

GARDNER, G. E., from 2278 Detroit Ave., to 1309 Palmetto, Toledo, O.

GILMOUR, M. L., from Reynolds Wire Co., to 2007 Everett St., Houston, Texas.

GRIFFITHS, E. M., from Universal Steel Co., Bridgeville, Pa., to 348 W. College St., Canonsburg, Pa.

HARTMAN, Wm. C., from 425 Avenue B, Bethlehem, Pa., to 616 S. Catalina Ave., Redondo Beach, Cal.

HEISE, A. R., from New Departure Mfg. Co., to General Delivery, Bristol, Conn.

HERB, J. W., from 729 Washington Street, Easton, Pa., to 98 Washington St., Phillipsburg, N. J.

HINDE, WILFRED, from Y. M. C. A., Moline, to 638 Forty-third St., Rock Island, Ill.

HOAGLAND, F. O., from Reed-Prentice Co., Worcester, Mass., to Saco Lowell Shops, Lowell, Mass.

HOGAN, E. J., from 2609 N. Main St., to Box 1227, Hughes Tool Co., Houston, Tex.

HOWE, H. A., from 4870 Edmonton Ave., Detroit, to 2218 W. 11th St., Terre Haute, Ind.

JARDINE, ROBT., from Rich Tool Co., Chicago, to 709 Kresge Bldg., Detroit, Mich.

JONES, A. R., from 425 E. Water St., Milwaukee, to Interstate Iron & Steel Co., 1401 Monroe Bldg., Chicago, Ill.

JONES, R. H., from 1400 Portland Ave., to 3016 29th Ave. S., Minneapolis, Minn.

KRUMM, S. Z., from Case School of Applied Science to 4912 E. 84th St., Cleveland, O.

LASCHUK, S., from 733 S. Karlov Ave., to 1644 Augusta, Chicago, Ill.

TRANSACTIONS

of the

American Society for Steel Treating

Vol. IV **Cleveland, September, 1923** **No. 3**

ON TO PITTSBURGH

THE Annual convention of the American Society for Steel Treating, to be held in Pittsburgh the week of October 8, gives promise of being the best attended of any of the four previous annual meetings. The large percentage of members attending is remarkable, and has occasioned much favorable comment. It is doubtful if any other technical society holding annual meetings, has as large a percentage of its members present. There must be, and is, a reason for this. It is because those who have once attended find the accruing benefits so voluminous and worth while that it would be the height of indifference to remain away. Not only have the attendants found there meat and satisfaction in the programs presented, but the International Steel exposition has always made a very lasting impression. Its educational value, and the wonderful possibilities of observing at first hand the latest and best products, materials and equipment for their use, serves as a magnet to draw them back to another convention. Nothing worth while is absent from the exposition, because all progressive, wide awake, firms are exhibiting. They represent the leaders in their lines just as those in attendance represent the leadership in the intellectual metallurgical thought of the country.

The annual meeting of the best minds at the A. S. S. T. convention is becoming more and more recognized as an essential part of the year's work. With the program and the exposition increasing both in quality and scope, the general benefits will of course be greatly enlarged, and the attendance should exceed the 20,000 that visited Detroit last year. Those who have attended previous conventions will be at Pittsburgh; those who have not, owe it to themselves, to step out with the leaders.

TILLMAN DAVIS LYNCH

National President of the American Society for Steel Treating

ALL HONOR

ONE quite frequently hears the statement made that those individuals who prepare papers for publication do so with an ulterior motive, in an endeavor to secure for themselves a large quantity of free advertising. Never was there a more unjust statement made with reference to those conscientious individuals who, because of ability and facilities are able to carry on research work in the line of their chosen occupations. Out of approximately three thousand members of the A. S. S. T. only eight per cent are represented as contributors of papers for the annual meetings or before local chapters. While there is no doubt that fifty per cent of the membership is capable of preparing interesting articles upon various phases of the work in which they are engaged, forty-two per cent have failed to embrace the opportunity. Those contributors to the various technical sessions of our society are conscious of the fact that money is not able to repay them for the amount of time, energy and effort necessary in the preparation of the work. If it is true, as many have been known to state, that it is so profitable from financial and advertising viewpoints to contribute papers to technical organizations, then it is surprising that a larger percentage does not avail itself of this golden opportunity.

There is no doubt that the preparation and presentation of a paper stamps the author as a progressive, live, wide awake and dependable thinker; an individual who is capable of preparing a piece of research work, carrying it to a successful conclusion and correlating his facts in a presentable and understandable manner and consequently his prestige and influence in the profession is correspondingly increased.

We should all bear in mind that we owe a great debt of gratitude to those individuals who are willing to give to the world the results of their own investigations. This willingness at once stamps them as above the ordinary type of individual who thinks and labors only for himself. And so we say "All Honor" to those who have prepared and are presenting papers for the various technical sessions of the A. S. S. T.

RESEARCH AND ITS APPLICATION

By T. D. Lynch

THE term "research" creates a vision of something new, the study and unfolding of problems hitherto unknown, or at least not well known. This conception of research is quite correct so far as it goes, but to the practical manager, the addition of the further important factor, the application of research to commercial problems, is made. We may, therefore, divide research into two main headings, namely, scientific and practical.

Scientific Research usually involves problems without known theories and laws, or but little known, and requires a careful study of fundamentals through extensive experimentation.

Practical Research comprises the application of the new laws and theories developed by the pure scientist, the correlation of all known data discovered and the employment of it in a specific manner, and thus render it useful for the service of man.

Scientific research without its practical application will carry us about as far as a locomotive without steam. It is, therefore, the object of this article to bring to the members of the American Society for Steel Treating, a picture of the possibilities and benefits that may be derived by the members who attend local chapter meetings, the annual convention and exhibition, who read TRANSACTIONS and then take the initiative in the problems that come to their individual plants, within the scope of the activities of each individual, by making sure that the proper materials are ordered and received, and then correctly processed and judiciously applied. It has been said that what we call "initiative" in a business man is called "skill" in a great surgeon. This is equally true of the making or the heat treating of steel. It is knowing the next move and moving at the right time.

We need sound theory, constructive practice, efficient organization, good tools and equipment, and proper materials, all of which must be planned logically and executed efficiently—the proper sequence for the efficient operations. When so equipped, the heat treater is in a position to produce consistent results. He has learned, by bitter experience, the need for uniform steel and by insistance he should be able to secure it by the adoption of proper

specifications, and rigid inspection. Research and the practical applications of chemistry and metallurgy have shown a definite procedure in the manufacture of steel necessary to obtain the type and grade needed—and to obtain it by a commercial process.

Metallography has also played a very important part in determining the best treatment for steels utilized to serve a given purpose. The grain size and structure, together with the chemical composition and physical properties, have been very important factors in this development. The scientist has been correlating and using such data for some years, until at this time the structure of steel that can be obtained by heat treatment, has become so well established that the practical heat treater at the furnace has begun to realize the true value and importance of grain structure and to realize that it is quite practical for him to maintain such temperatures and surrounding conditions as will produce the desired structure and corresponding physical properties.

The conditions of melting, refining, tapping and pouring of steel, especially the finer grades, are being studied and the proper methods and materials necessary to obtain the best quality are being worked out; also the proper working temperature and amount of reduction at the rolls or forge required to produce the best quality of each type are being determined.

Many of the more important steel manufacturers are alert to this growing need and there is apparently a great opportunity for the individual members of the American Society for Steel Treating to assist in solving the problem of the best steel and treatment for different applications.

The design engineers of the present day find it necessary to stress their materials far in excess of that formerly considered good practice and in view of this the material must be of the very highest order. It is quite necessary that they be assured that the material is as specified, in order to have it work safely at these additional stresses.

It is needless to say that from a commercial point of view, the manufacturer of steel, the manufacturer of machinery and the user of these products must find in them a commercially practical application and in our opinion this type of practical research is the type that the American Society for Steel Treating should devote

its attention to, through its National Research committee in conjunction with the research committees of the local chapters. There surely is a great field for this work and there is no other organization so well qualified to carry on this work as the American Society for Steel Treating. It is our sincere hope that especially those men connected with our different research committees will keep this in mind and prepare and discuss papers before our local chapters, our annual convention, and publish them in TRANSACTIONS.

HOTEL RESERVATIONS FOR THE CONVENTION

FOR the benefit of those who have not as yet made their hotel reservations during the period of the annual convention in Pittsburgh, October 8 to 12 inclusive, we are once more publishing the list of the principal hotels in Pittsburgh.

In writing to the hotel please state the price and kind of room you wish, and request them to acknowledge your communication confirming the reservation and price.

In case you have difficulty in securing the accommodations you wish, a communication addressed to the chairman of the hotels committee, R. E. Polk, chief industrial engineer, Equitable Gas Co., Pittsburgh, Pa., will receive prompt attention.

List of Pittsburgh Hotels

William Penn

(Headquarters)

375	Rooms	with bath,	2	persons,	Rate	$3.50-5.00	each
375	Rooms	with bath,	1	person,	Rate	4.00-8.00	

Fort Pitt

190	Rooms	with bath,	2	persons,	Rate	$2.50-5.00	each
100	Rooms	without bath,	2	persons,	Rate	2.50	each
190	Rooms	with bath,	1	person,	Rate	3.50-9.00	
100	Rooms	without bath,	1	person,	Rate	3.00	

Hotel Henry

12	Rooms	with bath,	4	persons,	Rate	$2.50	each
12	Rooms	with bath,	2	persons,	Rate	3.00	each
24	Rooms	with bath,	1	person,	Rate	4.00	up

WILLIAM PENN HOTEL
Convention Headquarters, Where the Morning Technical Sessions Will Be Held

Anderson Hotel

20	Rooms with bath,	4	persons,	Rate	$2.50	each
24	Rooms without bath,	4	persons,	Rate	2.00	each
10	Rooms without bath,	2	persons,	Rate	2.50	each
20	Rooms without bath,	1	person,	Rate	3.00	

General Forbes

17	Rooms with bath,	4	persons,	Rate	$2.00	each
9	Rooms with bath,	2	persons,	Rate	3.00	each
24	Rooms without bath,	2	persons,	Rate	1.50	each
25	Rooms with bath,	1	person,	Rate	4.00	up

Seventh Avenue Hotel

14	Rooms	with bath,	4 persons,	Rate	$2.50-3.00	each
10	Rooms	with bath,	2 persons,	Rate	2.50-3.00	each
20	Rooms	without bath,	2 persons,	Rate	2.00-2.50	each

Pittsburgh Natatorium

(For gentlemen only)

175	Rooms,	with swimming pool,	cots, 1 person,	Rate	$2.00	

Monongahela House

10	Rooms	with bath,	2 persons,	Rate	$3.00	each
40	Rooms	without bath,	2 persons,	Rate	2.00	each

Schenley Hotel

5	Rooms	with bath,	4 persons,	Rate	$3.00	each
10	Rooms	with bath,	2 persons,	Rate	4.00	each
10	Rooms	without bath,	2 persons,	Rate	3.00	each
10	Rooms	with bath,	1 person,	Rate	7.00	
10	Rooms	without bath,	1 person,	Rate	4.00	

Rittenhouse Hotel

25	Rooms	with bath,	2 persons,	Rate	$2.00-3.00	each
20	Rooms	with bath,	1 person,	Rate	3.00-4.00	

Y. M. C. A., East Liberty

10	Rooms	without bath,	1 person,	Rate	$2.00	

Negri Hotel

25	Rooms	with bath,	1 person,	Rate	$3.00	

New Sixth Avenue

15	Rooms	with bath,	2 persons,	Rate	$3.00-4.00	each
15	Rooms	without bath,	2 persons,	Rate	2.50-3.00	each
10	Rooms	with bath,	1 person,	Rate	3.00	
5	Rooms	without bath,	1 person,	Rate	2.00-3.00	

Chatham Hotel

5	Rooms	with bath,	4 persons,	Rate	$2.00	each
20	Rooms	with bath,	2 persons,	Rate	3.00-5.00	each
20	Rooms	without bath,	2 persons,	Rate	2.50-3.00	each
15	Rooms	with bath,	1 person,	Rate	3.00	

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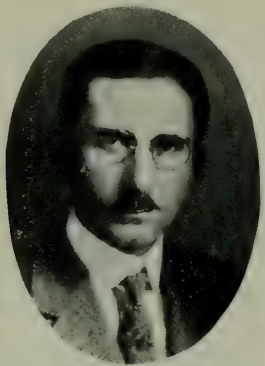

W. B. CROWE
Transportation Committee

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Information Committee

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J. TRAUTMAN, JR.
General Chairman

R. E. POLK
Hotels Committee

J. A. SUCCOP
Ladies Entertainment Committee

W. A. BUECHNER
Local Exhibition Committee

SOME OF THE CHAIRMEN OF THE PITTSBURGH LOCAL CONVENTION COMMITTEE

OUTLINE OF EVENTS

FIFTH ANNUAL CONVENTION A. S. S. T.

All morning technical sessions will be held in the ball room of the William Penn Hotel. The afternoon sessions will be held in the meeting room at Motor Square Garden.

Monday, October 8th

10:00 A. M.—Technical Session, Ball Room, Wm. Penn Hotel.
1:00 P. M.—Exposition Opens. Registration Begins.
3:30 P. M.—Technical Session, Motor Square Garden.
7:00 P. M.—Moving Pictures.

Exposition open from 1:00 P. M. to 10:00 P. M.

Tuesday, October 9th

9:30 A. M.—Technical Session, Ball Room, Wm. Penn Hotel.
12:10 P. M.—Plant Visitation, Westinghouse Electric & Mfg. Company.
1:00 P. M.—Exposition Opens.
3:30 P. M.—Round Table Discussion, Motor Square Garden.
7:00 P. M.—Moving Pictures.
9:30 P. M.—Smoker and Entertainment, Ball Room, Wm. Penn Hotel.

Exposition open from 1:00 P. M. to 10:00 P. M.

Wednesday, October 10th

9:30 A. M.—Annual Meeting of the Society, Ballroom William Penn Hotel.
1.00 P. M.—Exposition Opens.
2.00 P. M.—Plant Visitation, Homestead Works, Carnegie Steel Co.
3:30 P. M.—Round Table Discussion and Technical Session, Motor Square Garden.
7:00 P. M.—Moving Pictures.
9:30 P. M.—Annual Dance, Ball Room, Wm. Penn Hotel.

Exposition open from 1:00 P. M. to 10:00 P. M.

Thursday, October 11th

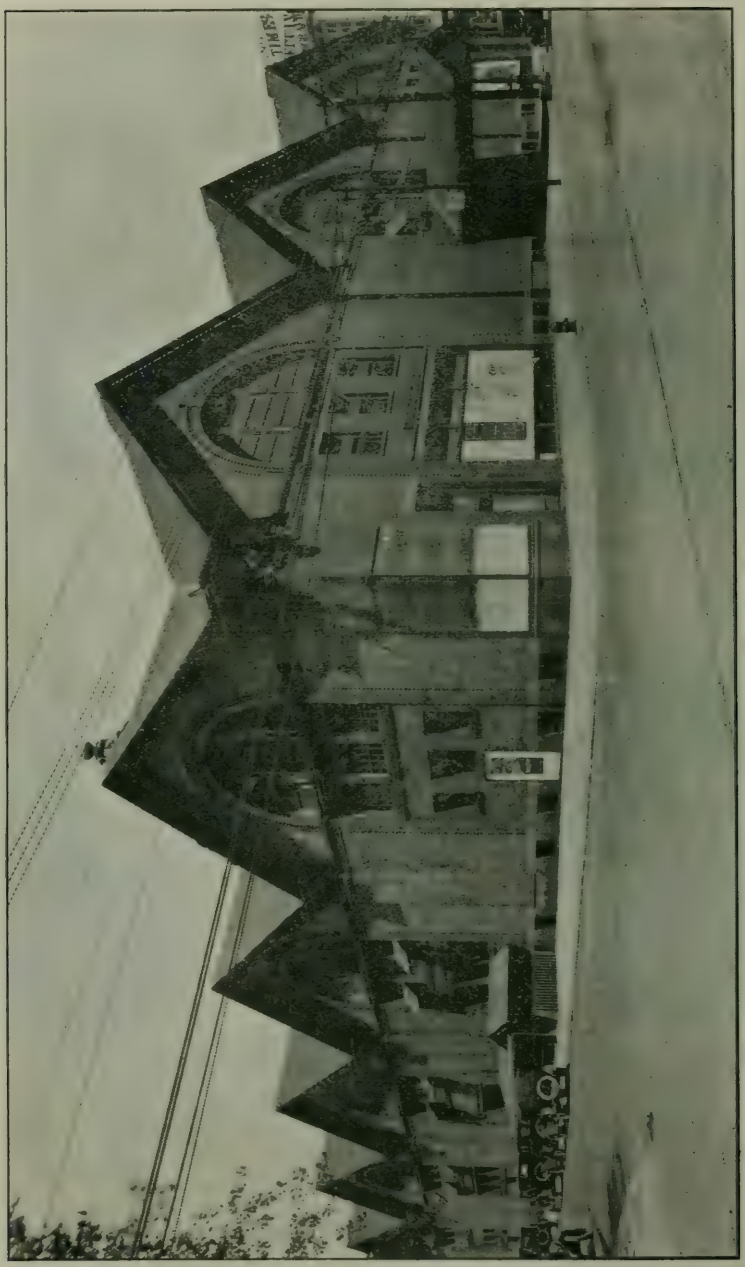
9:30 A. M.—Technical Session, Ball Room, Wm. Penn Hotel.
10:00 A. M.—Exposition Opens.
2:30 P. M.—Hardness Testing Symposium, Motor Square Garden.
5:30 P. M.—Exposition Closes.
6:30 P. M.—Annual Banquet of the American Society for Steel Treating, English Room, Fort Pitt Hotel. Tickets at Registration Desk.

Exposition open from 10:00 A. M. to 5:30 P. M.

Friday, October 12th

9:30 A. M.—Technical Session, Ball Room, Wm. Penn Hotel.
10:00 A. M.—Exposition Opens.
12:00 M.—Plant Visitation, National Tube Works, McKeesport, Pa.
2:30 P. M.—Symposium on Metallurgical Education.
7:00 P. M.—Moving Pictures and Band Concert.

Exposition open from 10:00 A. M. to 10:00 P. M.



Motor Square Garden, Where the Exposition and the Afternoon Technical Sessions Will Be Held

LADIES' ENTERTAINMENT

Ladies' headquarters will be at the Wm. Penn Hotel. Visiting ladies should report at headquarters as soon as possible after arrival in the city and indicate in which activities they desire to participate.

Before all trips, visits or parties, the ladies will first meet at their headquarters in the Wm. Penn Hotel.

Monday, October 8th

No special activity is planned for the ladies on Monday, the time being left open in order that they may familarize themselves with the shopping district as well as visit the exposition.

Tuesday, October 9th

2:00 P. M.—Auto Ride to Points of Interest in and about Pittsburgh.

8:00 P. M.—Theatre Party.

Wednesday, October 10th

12:00 M.—Luncheon and Trip of Inspection Through Heinz Pickle Factory.

9:30 P. M.—Annual Dance of the American Society for Steel Treating in the Ball Room of the Wm. Penn Hotel.

Thursday, October 11th

2:00 P. M.—Auto Ride.

6:30 P. M.—Ladies are invited to participate in the Annual Banquet of the American Society for Steel Treating to be held in the English Room, Fort Pitt Hotel.

TENTATIVE PROGRAM, FIFTH ANNUAL CONVENTION, AMERICAN SOCIETY FOR STEEL TREATING, PITTSBURGH. OCTOBER 8-12, 1923

Note: Registration begins at 1 p.m. at Registration Desk, Motor Square Garden.

MONDAY, OCTOBER 8

Morning Session

Meeting in Ball Room, William Penn Hotel.

10:00 A. M.—Chairman ..... W. J. Merten
Address of Welcome .....J. Trautman, Jr.
Welcome to Pittsburgh .....Mayor Wm. Magee
Response.....Pres. T. D. Lynch

Technical Session

The Manufacture of Automobile Leaf Springs—C. G. Shontz, Metallurgist, Perfection Spring Company, Cleveland.

Metallography and Testing of Oxyacetylene Welds—J. R. Dawson, Research Metallurgist, Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y.

Some Observations on Furnaces and Fuels, Including the Electric Furnace for Heat Treating—E. F. Collins, Consulting Engineer, General Electric Company, Schenectady, N. Y.

The Tempering of Tool Steels—J. P. Gill and L. D. Bowman, Metallurgists, Vanadium Alloys Steel Company, Latrobe, Pa.

Abnormal Grain Growth in Cold Rolled Low Carbon Steel—V. E. Hillman and F. L. Coonan, Metallurgist and Assistant Metallurgist, Crompton & Knowles Loom Works, Worcester, Mas. (To be presented by title.)

Afternoon Session

1:00 P. M.—Exposition opens.

3:30 P. M.—Technical Session—Motor Square Garden.

The Annealing of Sheet Steel—Francis G. White, Metallurgical Engineer, National Enameling & Stamping Company, Granite City, Ill.

Sheet Steel for Automotive Purposes—Harry Martin, Metallurgical Department, Dodge Bros., Detroit.

The Manufacture of Sheet Steel—J. H. Nead, Research Metallurgist, American Rolling Mills Company, Middletown, Ohio.

Automobile Sheet Steel Specifications—H. M. Williams, Metallurgist, General Motors Research Corporation, Dayton, Ohio.

Evening Session

Exposition open until 10 p.m.

7:00 P. M.—Moving Pictures.

TUESDAY, OCTOBER 9

Morning Session

Meeting in Ball Room, William Penn Hotel.

9:30 A. M.—Technical Session.

Measurement of Carbon Penetration in Carburized Steels—S. P. Rockwell, Consulting Metallurgist, Hartford, Conn., and Frederick Downs, Chemist, New Britain Machine Company, New Britain, Conn.

Case Hardening and Other Heat Treatments as Applied to Gray Cast Iron—H. B. Knowlton, Instructor, Central Continuation School, Milwaukee, Wis.

The Influence of Barium Carbonate upon Wood Charcoal used for Cementation—B. F. Shepherd, Metallurgical Department, Ingersoll-Rand Company, Phillipsburg, N. J.

Protective Coatings for Selective Carburization—J. S. Vanick and H. K. Herschman, Metallurgist and Assistant Physicist, Bureau of Standards, Washington.

Investigation of the Treatment of Steel for Permanent Magnets—R. L. Dowdell, Instructor in Metallography, University of Minnesota, Minneapolis, Minn.

The Thermal Treatment of the Light Alloys of Aluminum and Copper—A. M. Portevin and Francois LeChatelier, Paris, France. (To be presented by title).

Afternoon Session

12:10 P. M.—Plant Visitation, Westinghouse Electric & Manufacturing Co.

1:00 P. M.—Exposition opens.

3:30 P. M.—*Round Table Discussion under Direction of Standards Committee*, Motor Square Garden.

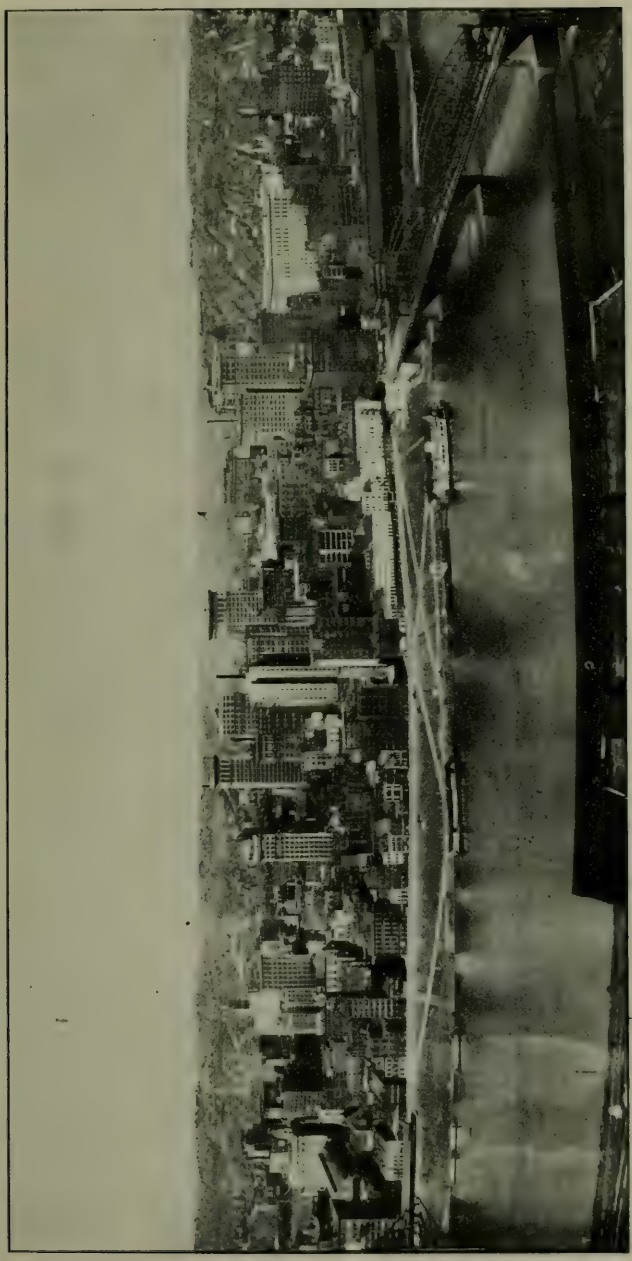
Chairman.....R. M. Bird

Evening Session

Exposition open until 10 p.m.

7:00 P. M.—Moving Pictures.

9:30 P. M.—Annual Smoker and Entertainment, Ball Room, William Penn Hotel.



Pittsburgh Skyline from Mt. Washington.

WEDNESDAY, OCTOBER 10

Morning Session

Annual Meeting of the Society, Ball Room, William Penn Hotel.

9:30 P. M.—Chairman .....T. D. Lynch
Report of Tellers of Election .....C. G. Shontz
President's Address .....T. D. Lynch
Report of Treasurer .....J. V. Emmons
Report of Secretary .....W. H. Eisenman
Report of National Committees
Standards .....R. M. Bird
Constitutions and By-Laws .....S. M. Havens
Report of Chapter Delegates

Afternoon Session

1:00 P. M.—Exposition opens.
2:00 P. M.—Plant Visitation, Homestead Works, Carnegie Steel Company.
3:30 P. M.—Round Table Discussion and Technical Session on Heavy Forgings, Motor Square Garden.

The Manufacture of Heavy Forgings—W. R. Klinkicht, Foreman, Heat Treating Department, Pollak Steel Company, Cincinnati.

Determining Heat Treating Costs—H. F. Wood, Metallurgist, Wyman-Gordon Company, Ingalls-Shepard Division, Harvey, Ill.

Spark Testing of Steel—Don Stacks, Consulting Metallurgical Engineer, Hartford, Conn.

Some Fundamental Defects of Hardened Steels—Dr. Leslie Aitchison, Birmingham, England.
(To be presented by title).

Evening Session

Exposition open until 10:00 P. M.
7:00 P. M.—Moving Pictures.
9:30 P. M.—Informal Dance, Ball Room, William Penn Hotel.

THURSDAY, OCTOBER 11

Exposition opens at 10:00 A. M.
9:30 P. M.—Technical Session, Ball Room, William Penn Hotel.
Chairman .....H. M. Boylston

Effect of Heat Treatment on Lathe Tool Performance and Some Other Properties of High-Speed Steels—H. J. French, Physicist, Bureau of Standards, Washington, Jerome Strauss, Materials Engineer, U. S. Naval Gun Factory, Washington, and T. G. Digges, Assistant Physicist, Bureau of Standards, Washington.

Secondary Hardness in Austenitized High Chromium Steels—E. C. Bain, Research Metallurgist, Atlas Steel Corporation, Dunkirk, N. Y.

The Hardening of Steel—Zay Jeffries and R. S. Archer, Research Bureau, Aluminum Company of America, Cleveland.

Crystallization of Iron and Its Alloys—Albert Sauveur,

Professor of Metallurgy, Harvard University, Cambridge, Mass.

X-Ray Examinations of Steel Castings—F. C. Langenberg, Metallurgist, Watertown Arsenal, Watertown, Mass.

Afternoon Session

2:30 P. M.—Technical Session, Motor Square Garden. *Hardness Testing Symposium*, National Research Council. Maj. A. E. Bellis, Chairman.

The Hardness of "Common High" Sheet Brass—A. L. Davis, Metallurgist, Scovill Mfg. Company, Waterbury, Conn.

Magnetic Indications of Hardness and Brittleness—A. V. deForest, Research Department, American Chain Company, Bridgeport, Conn.

Testing of Steel for Hardness—H. M. German, Metallurgist, Henry Disston & Sons, Inc., Philadelphia.

5:30 P. M.—Exposition closes.

Evening Session

6:30 P. M.—*Annual Banquet of the American Society for Steel Treating*, English Room, Fort Pitt Hotel. Tickets at Registration Desk.

FRIDAY, OCTOBER 12

Morning Session

Exposition opens at 10:00 A. M.

9:30 A. M.—Technical Session, Ball Room, William Penn Hotel.
Chairman .....Paul D. Merica

Salt Baths and Containers—Sam Tour, Metallurgist, Doehler Die Castings Company, Brooklyn, N. Y.

The Physical Properties of Metals at Elevated Temperatures—Vincent T. Malcolm, Metallurgist, Chapman Valve Mfg. Company, Indian Orchard, Mass.

The Ageing of Steel—W. P. Wood, Department of Metallurgy, University of Michigan, Ann Arbor, Mich.

Conical Illumination in Metallography—H. S. George, Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y.

Carbon and Carbon—Vanadium Steel Castings—A comparison—J. M. Lessells, Metallurgist Engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh.

The Theory of Quenching in Steels—Kotaro Honda, Tohoku Imperial University, Sendai, Japan. (To be presented by title).

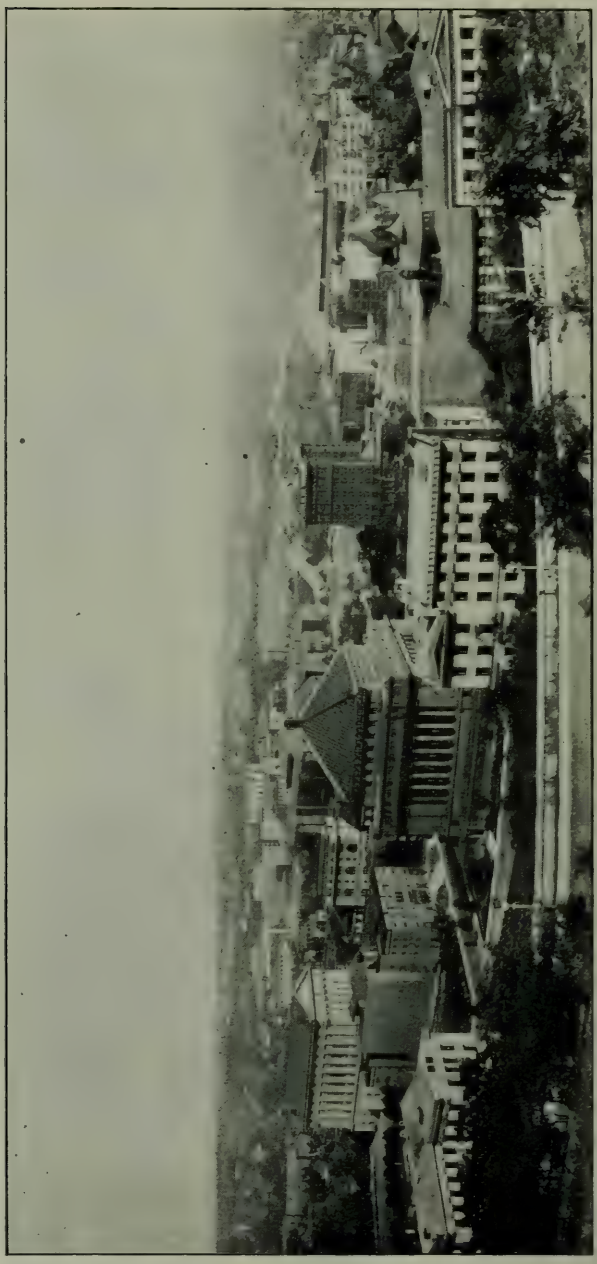
12:00 M.—Plant Visitation, National Tube Works, McKeesport, Pa.

Afternoon Session

2:30 P. M.—Motor Square Garden.
Symposium on Metallurgical Education.
Chairman .....Prof. S. L. Goodale

Evening Session

7:00 P. M.—Band Concert.
10:00 P. M.—Exposition Officially Closes.



Schenley Farms District showing Carnegie Tech, University of Pittsburgh, Carnegie Institute, Bureau of Mines, Masonic Temple, Memorial Hall, Syria Mosque, Pittsburgh Athletic Association Hotel Schenley, Mellon Institute and Forbes Field

LIST OF EXHIBITORS AND WHAT THEY WILL EXHIBIT AT THE INTERNATIONAL STEEL EXPOSITION, PITTSBURGH, OCTOBER 8-12, 1923

Air Reduction Sales Co., New York City. Space 137 will exhibit: apparatus and supplies. Airco-D-B specially designed machines for oxyacetylene cutting.
In charge of booth: H. H. Melville.

American Car & Foundry Company, New York City. Space 69 will exhibit:
One, No. 3 Three-Electrode Berwick Electric Rivet Heater for heating rivets up to 1⅛ inches in diameter and of any length up to 7¾ inches.
One, No. 4 Two-Electrode Berwick Electric End-Rod Heater for heating any size and diameter rod up to 1½ inches in diameter and giving any length of heat desired up to 8 inches.
One, 4 foot Rod Heater for heating any diameter rod up to 1⅛ inches, length of heat 4 feet.
In charge of booth: John S. Helt, Wilson Helt and F. C. Cheston.

American Gas Furnace Company, Elizabeth, N. J. Space S105 will exhibit:
Complete line of products.
In charge of booth: P. C. Osterman.

American Tool Works Company, Cincinnati. Space 92 will exhibit:
Lathes, Planers, Shapers, Radial Drills, etc.

American Stainless Steel Company, Pittsburgh. Space S116 will exhibit:
Articles made from stainless steel.
In charge of booth: John C. Neale.

Armstrong Blum Mfg. Company, Chicago. Space 78 will exhibit:
"Marvel" Hack Saw Machines; Automotive High-Speed Saw, Metal Band Saw, Punching, Shearings and Bending Machine.
In charge of booth: Harry J. Blum, secretary and George J. Blum, vice president.

Armstrong Cork & Insulation Company, Pittsburgh. Space 52 will exhibit:
Nonpareil Insulating Brick for furnaces, ovens, etc.
Nonpareil High Pressure Covering, blocks and cement for steam lines and other heated equipment.
Nonpareil Cork Covering for refrigerated lines and tanks.
Nonpareil Corkboard for cold storage and constant temperature rooms.
Linotile and Armstrong's Cork Tile for floors.
In charge of booth: R. S. Findley, L. W. Bertelsen and F. C. Young.

E. C. Atkins & Co., Indianapolis, Ind. Space 123 will exhibit:
Complete line of metal-cutting saws which includes KWIK-KUT power hack saw machine, metal band saw machine, circular metal-cutting saws, metal-slitting saws, hack saw blades, hack saw frames and Cantol belt wax. Metal-cutting machines will be in operation. Free samples of Cantol belt wax will be distributed.
In charge of booth: Edward S. Norvell, manager, metal-cutting department; W. R. Chapin, metallurgist; W. H. Albaugh, Pittsburgh

salesman; Claude E. Drake, St. Louis salesman and C. Fred Klee, Indianapolis salesman.

F. C. Andresen & Associates, Inc., Pittsburgh. Space S142 will exhibit:
Publication "Fuels and Furnaces". Booth will also be used for reception purposes.
In charge of booth: F. C. Andresen, president.

Atlas Steel Corporation, Dunkirk, N. Y. Space 19 will exhibit:
Various grades of tool steel and special steels. One case will show fractures of the standard grades of tool steel in the annealed and hardened condition. Special cases will show various finished products made from Atlas high-speed steel, stainless and chrome bearing steels.
Drill Rod and other products from cold drawing department.
In charge of booth: S. T. Harleman, H. R. Reese, H. R. Williams, C. V. Reilly, all from the sales department and M. A. Grossmann, E. C. Bain and W. H. Wills from metallurgical department.

Avey Drilling Machine Company, Cincinnati, Ohio. Space 59 will exhibit.
One, No. ½ Avey Ball Bearing Drilling Machine, column type.
One, No. 2 Avey Ball Bearing Drilling Machine, column type.
One, No. 3 special Avey Ball Bearing Drilling Machine column type, power feed.
In charge of booth: J. G. Hey, vice president.

Babcock & Wilcox Tube Company, Beaver Falls, Pa. Space S107 will exhibit:
Seamless Steel Tubes.
In charge of booth: H. N. Murray, superintendent.

Bacharach Instrument Company, Pittsburgh: Space 99B will exhibit:
Complete line of products.
In charge of booth: L. J. Speidel, treasurer.

Baker Brothers, Toledo, Ohio. Space 89 will exhibit:
Drilling machine.
In charge of booth: W. W. Elliott and H. L. Tigges.

Bausch & Lomb Optical Co., Rochester, N. Y. Space 5 will exhibit:
A new model of the large metallographic outfit on which will be incorporated a number of new and unique features. Also three smaller models of a new or at least modified design. Usual line of metallurgical microscopes and accessories of interest to the metallurgist.
In charge of booth: W. L. Patterson and I. L. Nixon.

Bellevue Industrial Furnace Company, Detroit. Space 96 will exhibit:
Vertical complete muffle gas fired high speed furnace with muffle made of Carbofrax manufactured by the Carborundum Company operating in connection with Geissinger Fuel Control Valve, and Brown Recording Instrument.
One Aluminum Melting Furnace, tilting type, Geissinger Fuel Control Valve, Bellevue Oil and Gas Burners and Bellevue special shapes fire brick.
In charge of booth: Walter E. Hinz, Louis J. Raymo and H. G. Geissinger.

Bellis Heat Treating Company, New Haven, Conn. Space 30-A will exhibit:

Bellis Lavite—the ideal heating medium for hardening and tempering carbon, high speed and alloy steels.

In charge of booth: A. E. Bellis, president and J. W. Black, superintendent.

Bethlehem Steel Company, Bethlehem, Pa. Space 14-23 will exhibit:

The vast quantities of raw materials required by modern steel making organizations of large size.

Coke Works Practice, showing the amount of coal required to produce one ton of coke and the amounts of the various by-products obtained in the operation.

Blast Furnace Practice. The amount of raw materials required to produce and the resulting products obtained in the making of one ton of pig iron.

Open Hearth Practice. Alloy Steel Heat. The materials required to produce one ton of alloy steel.

Samples of all raw materials, products and by-products will form a part of the exhibit.

In charge of booth: R. M. Bird, A. P. Spooner, R. Shimer, G. C. Lilly, C. E. Chamberlain, R. H. Christ and G. A. Richardson.

Blanchard Machine Company, Cambridge, Mass. Space 85 will exhibit:

Blanchard No. 10 Vertical Surface Grinding Machine, direct motor-drive type with caliper attachment.

Samples of work finished by grinding machine.

Photograph of other sizes of Blanchard Surface Grinding Machines and work done by them with production data. The machine will be in operation on real work, giving visitors the opportunity to study its operation as well as the results obtained.

This exhibit will be located in Motch & Merryweather Machinery Company's Model Shop.

In charge of booth: F. E. Bartley.

Bristol Company, Waterbury, Conn. Space 99 will exhibit:

Bristol's Indicating and Recording High and Low Temperature Automatic Controllers, Pyrometers, Thermometers, Gages, etc.

In charge of booth: H. L. Griggs.

Brown Instrument Company, Philadelphia, Pa. Space 9 will exhibit:

Added to the standard line of Brown Indicating and Recording Pyrometers, Thermometers, Pressure Gauges, and Tachometers, the following new instruments will be of keen interest to metallurgical engineers: Brown Hydrogen Ion Recorders, Alkalinity and Acidity Recorders, Oxygen Contact Recorders and Indicating and Recording Temperature Control, Signaling and Alarm instruments.

Also the new Brown Electric CO_2 Recorder, which does away with the limitation of CO_2 Recorders operative on other principles. These instruments will be actually demonstrated so that anyone will have a comprehensive idea of their installation, simplicity and ruggedness.

All other standard Brown Instruments such as Radiation Pyrometers, Portable Potentiometers, etc., will be shown.

In charge of booth: Richard P. Brown, president; George W. Keller, sales manager; G. L. Clapper, Pittsburgh district manager; F. Q. Thorp, Cleveland district manager; D. C. Mayne, Columbus district manager; A. C. Hanson, Pittsburgh district representative; and P. E. Hemmerle, pyrometer engineer.

The College of Engineering—Carnegie Institute of Technology.

Carnegie Institute—Schenley Park and Forbes Street. The largest and finest institute of Art and Museum of Natural History in the United States. It has a Museum with one of the largest collections of Fossils, Prehistoric Relics and Ethnological subjects ever assembled, a Library of 300,000 volumes, and a Music Hall with one of the world's best pipe organs. It is open to the public daily from 10 A. M. to 10 P. M., Sundays from 2 to 6 P. M.

Bullard Machine Tool Company, Bridgeport, Conn. Space 87 will exhibit:
Machines they manufacture.

Bureau of Standards, Washington, D. C. Space S104 will exhibit:
Equipment available at the Bureau of Standards for research and testing and illustrating the fields of co-operation with various industries.
Special attention will be paid to metallurgical work and in particular that relating to irons and steels, but the work of the paper, textile, rubber, leather, cement and optical glass sections will also be illustrated.
There will be on hand a case containing standard chemical samples, a set of the Bureau's precision gage blocks and a relatively large number of samples to illustrate metal spraying by methods recently perfected at the Bureau.
Researches considered of special interest to members of the Society and their guests will also be illustrated by small models or photographs and transparencies. These will include determinations of thermal stresses in chilled iron and steel car wheels, properties of metals at high temperatures, and photomicrographs of carbon and alloy steels, etc.
Sets of publications will be at hand for examination by those interested.
There will be installed and in continuous operation a projection lantern which will permit a more complete demonstration of the field of activities of the Bureau.
In charge of booth: G. K. Burgess, H. J. French, T. G. Digges and O. Z. Klopsch.

The Calorizing Company, Pittsburgh. Space 47 will exhibit:
Furnaces equipped with Calorized Tube Recuperators.
Powder Calorized Pipe, etc., Dip Calorized Sheets, Castings, etc.
Calite (High Temperature Resisting) Castings.
In charge of booth: G. L. Davis, Jos. Karch, J. S. Stairs, B. J. Sayles, G. D. Mantle, B. L. Jarrett, A. V. Farr, E. L. Malone, W. E. Clark, C. H. Evans and S. F. Cox.

The Case Hardening Service Company, Cleveland. Space 38 will exhibit:
Bohnite Case Hardening compound. The original impregnated carbonizer, exhibited at every Steel Treating Exhibition to date—the compound which has become the standard of comparison.
Caseite, the scientific cyanide mixture. Made under rigid chemical supervision and inspection. Manufactured since 1915.
Non-Case Anticarburizing Paint, for localizing case hardening and for the protection of steel from absorption of carbon.
In charge of booth: W. C. Bell, E. J. Gossett and J. S. Ayling.

Celite Products Co., Chicago. Space 1 will exhibit:
Complete display of Sil-O-Cel heat insulation showing the following products: Sil-O-Cel insulating brick for direct temperatures up to 1600 degrees Fahr., Sil-O-Cel C-22 for direct temperatures in excess of 2200 degrees Fahr.; Sil-O-Cel powder, C-3, block and cements. Also standard blow torch test in which a blow torch plays upon a Sil-O-Cel insulating brick continuously to illustrate the impenetrability of Sil-O-Cel to heat flow. Also blueprints and illustrations as well as actual samples of heat treating furnaces, enameling ovens, etc., showing method of installing Sil-O-Cel heat insulation.
In charge of booth: W. T. Kennedy and others.

Central Steel Co., Massillon, Ohio. Space 35 will exhibit:
Typical scenes of steel mill practice shown in enlarged photographs. Representative specimens of heat treated parts made from Agathon Alloy Steels will be shown.
In charge of booth: F. J. Griffiths, president and general manager; J. M. Schlendorf, vice president in charge of sales; B. F. Fairless, vice president in charge of operations; E. C. Smith, chief metallurgical engineer; C. P. Richter, E. H. Kottnauer and W. W. Leffler all of the metallurgical department.

Champion Sales Company, Pittsburgh. Space S112 will exhibit:
Metal Window Ventilators, and other special products.
In charge of booth: E. C. Sattley, vice president.

Chicago Flexible Shaft Company, Chicago. Space 98 will exhibit:
In operation Crucible Furnace, Triple unit, Oven Furnace and High Speed Steel Furnace.
In charge of booth: Peter Blackwood, J. W. Lazear and O. C. Bernhard.

The Cincinnati Grinder Company, Cincinnati, O. Space 90 will exhibit:
One—12″ x 36″ Cincinnati Universal Grinding Machine, motor-driven.
One—Special heavy duty headstock for die work and one set of speed change and reverse units.
In charge of booth: Arthur C. Hoefinghoff and Walter F. Stegner.

Cincinnati Milling Machine Company, Cincinnati, Ohio. Space 90 will exhibit:
One, No. 4 Vertical Cincinnati Milling Machine arranged for motor drive in operation, demonstrating the capacity of this machine to do face milling on heavy profiling work.
One, new model No. 2 Universal High Power Miller with the new rectangular overarm.
One Cincinnati Centerless Grinder in production on straight through and shoulder grinding.
One Cincinnati 12 x 36 inches Universal Cylindrical Grinder on typical tool room work.
One Cincinnati No. 1½ Cutter Grinder together with a selection of cutters capable of being ground on the machine.
In charge of booth: Walter W. Tangeman, George Binns and L. V. Johnson.

Cleveland Steel Tool Co., Cleveland. Space 36B will exhibit:
Punches, dies, pneumatic chisel blanks and rivet sets.
In charge of booth: R. J. Venning, treasurer.

Climax Molybdenum Company, New York City. Space 53-62 will exhibit:
Molybdenum Steel and products made from same.
In charge of booth: B. F. Phillipson, president; J. D. Cutter, vice president and metallurgist; and W. N. Bratton, sales metallurgist.

Colonial Steel Company, Pittsburgh. Spaces 33-42 will exhibit:
Tool Steel and special open-hearth steels, hardened fractures, raw materials and alloys used in process of manufacture, heat treating methods, etc.
In charge of booth: Lawrence Wood, manager of Pittsburgh district sales.

Combustion Utilities Corporation, New York City. Space 94-95 will exhibit:

A number of furnaces illustrating general heat treating equipment among which will be Tool Heating Furnaces, Oil and Lead Tempering Baths, and Heat Treating Furnaces both Recuperative and Non-Recuperative with which it is hoped to illustrate the advantages of the recuperator by having two such furnaces automatically controlled and fired with sufficient indicating and recording instruments to show the comparative economy of the two types of furnaces. Also one or two small but complete models of larger Heat Treating and Forging Furnaces.

In charge of booth: H. M. Henry, W. L. Frederick, P. J. Nutting, F. W. Manker and W. B. Kopfer.

Crescent Washing Machine Company, New Rochelle, N. Y. Space 93 will exhibit:

In operation—Model No. 1A machine for cleaning metal parts of every description, for cleaning castings and forgings, stampings, screw machine products, etc.

In charge of booth: E. C. Arndts and J. F. Donovan, sales manager.

Crucible Steel Company of America, New York City. Space 13 will exhibit:

Tool and Alloy Steels and products made therefrom.

In charge of booth: Dr. John A. Mathews, president; C. M. Johnson, director research department; and J. W. Taylor, Pittsburgh office.

Cutler Steel Company, Pittsburgh. Space S111 will exhibit:

Duraloy-Castings, Sheets, Bars and Wire; finished and semifinished parts.

In charge of booth: T. R. Heyward Jr., W. H. Waddington, F. B. Foster, G. C. Shidle and A. S. Lambie.

Dearborn Chemical Company, Chicago. Space 41 will exhibit:

NO-OX-ID, Rust Preventive, chemical 41 compounded Klean Kleen, Powdered Cleaner, in different grades, Cutting Oils, Drawing Oils, Quenching Oils, Soluble Cutting Oil and Deraboline, liquid cleaner.

In charge of booth: E. M. Converse, director of department of specialties, Chicago; J. A. Crenner, manager Pittsburgh office; C. C. Brown, Pittsburgh; E. K. Thomas, Pittsburgh and C. I. Loudenback, Detroit office.

Dempsey Furnace Company, New York City. Space 97 will exhibit:

High-speed steel furnace; complete line of gas and oil burners; electric constantator, for controlling oil, gas or steam pressure.

In charge of booth: H. B. Dempsey and F. J. Spillane.

Henry Disston & Sons, Inc., Philadelphia. Space S115 will exhibit:

Milling saws, hot saws, friction saws, files, hack saws, tools and Higley milling saw machine.

In charge of booth: J. L. Dorrington, Walter Newman and E. S. Ludy.

Driver-Harris Company, Harrison, N. J. Space 4 will exhibit:

Nichrome, heat resisting castings, carbonizing boxes, Nichrome sheets for furnace linings and Nichrome resistance wire.

In charge of booth: Arlington Bensel, vice president; W. E. Blythe, Detroit district manager; H. D. McKinney, Chicago district manager; A. M. Morgan, J. B. Shelby and H. O. Hardegan.

Electrical Refractories Company, East Palestine, Ohio. Space S101A will exhibit:
Electrical refractories for use in resistance-type electric heating devices, including electric ranges, steel treating furnaces enameling ovens, immersion heaters and laboratory equipment.
In charge of booth: F. E. Owen.

Charles Engelhard, Inc., New York City. Space 32 will exhibit:
Thermo-Electric Pyrometers, Indicators, Recorders, Base-metal Thermo-Couples, Rare-metal Thermo-Couples, Pyrometer tubes, Electric Thermometers, Indicators and Recorders, Automatic Temperature Regulators; Temperature, gas and oil, Electric Gas Recorders (Thermal Conductivity type), Thermal Expansion Measurement Apparatus, Refractory Porcelain.
In charge of booth: J. H. Allison, E. S. Newcomb, E. J. Deckman, R. W. Newcomb.

Equitable Gas Company, Pittsburgh. Space S130 will exhibit:
Curves, Bulletins and descriptive matter relating to utilization of natural gas.
Complete information will be given and all questions answered regarding supply and use of natural gas for heating and other industrial purposes.
In charge of booth: R. E. Polk, C. H. Whitwell, E. F. Koch, E. L. Flowers and C. J. Long.

Federal Machine & Welder Company, Warren, Ohio. Space S119 will exhibit:
Electric Butt Welding Machine.
In charge of booth. Fred P. McBerty, general manager.

A. Finkl & Sons Company, Chicago. Space 53 will exhibit:
Drop Forge supplies, Mo-lyb-die steel products, die blocks and piston rods.
In charge of booth: Chas. E. Finkl, manager, Wm. Finkl, E. H. Graham, manager, Detroit district, and T. P. Wallace, sales.

Firth Sterling Steel Company, McKeesport, Pa. Space 3 will exhibit:
Blue Chip High Speed and other Firth-Sterling tool and die steels; also Firth-Sterling (S-Less) Stainless Steel.
In charge of booth: Edwin T. Jackman, G. A. Jacobs, W. A. Nungester, W. C. Royce, David E. Jackman, Jr., Donald G. Clark, H. I. Moore, A. E. Barker and Harry Jarvis.

J. B. Ford Company, Wyandotte, Mich. Space 31 will exhibit:
"Wyandotte" cleaning materials with tank showing method of agitating a cleaning solution.
In charge of booth: C. S. Tompkins and L. C. Warden.

Forging-Stamping-Heat Treating, Pittsburgh. Space 43 will exhibit:
Copies of their four publications, Forging-Stamping-Heat Treating formerly (Forging and Heat Treating); Blast Furnace and Steel Plant; Coal Industry; Directory of Iron, Steel, Forging, Stamping and Heat Treating plants.
In charge of booth: L. L. Carson, D. L. Mathias, F. J. Crolius, A. M. Mitchell and George P. Grant.

General Alloys Co., Boston. Space 28 will exhibit:
Q-Alloy Heat treating containers, boxes, pots, retorts and castings.
In charge of booth: H. H. Harris, E. P. Van Stone, W. K. Leach and A. L. Grinnell.

General Electric Company, Schenectady, N. Y. Space 76-77 will exhibit:
Two small electric furnaces and one air drying oven.
In charge of booth: C. T. McLoughlin, E. F. Collins, and C. L. Ipsen.

Giddings & Lewis Machine Tool Company, Fond du Lac, Wis. Space 86 will exhibit:
One No. 32 Horizontal Boring Machine.

Goddard & Goddard Company, Detroit. Space 79 will exhibit:
Complete line of Milling Cutters.
In charge of booth: A. N. Goddard, president and C. S. Goddard, sales manager.

Gould & Eberhardt, Irvington, N. J. Space 85 will exhibit:
One, 32 inch Invincible motor-driven shaper.
In charge of booth: C. L. Cameron and A. Miller.

Geo. J. Hagan Company, Pittsburgh. Space 66 will exhibit:
Improved design of standard box type electric furnace with automatic control equipment.
In charge of booth: R. E. Talley, C. F. Cone, R. L. Corbett, F. W. Robertson and A. D. Dauch.

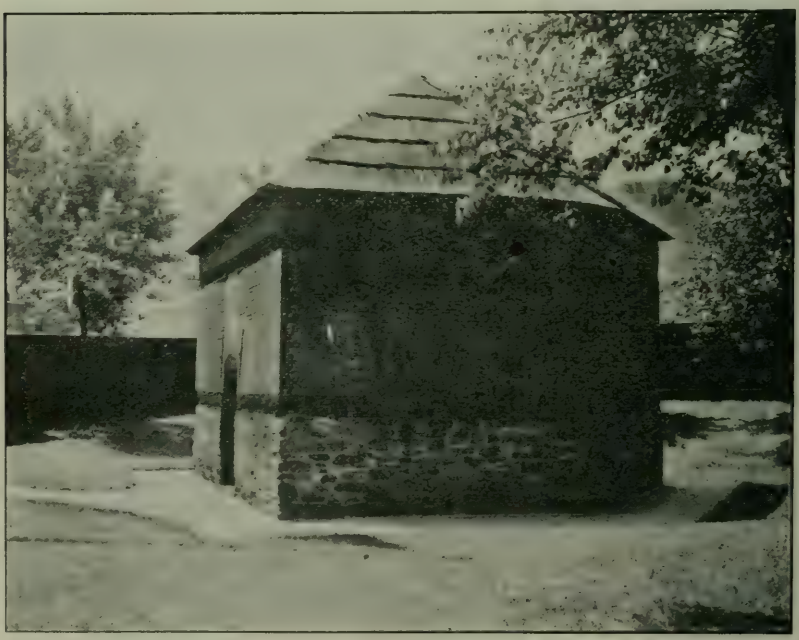
Halcomb Steel Company, Syracuse, N. Y. Space 22 will exhibit:
Complete line of tool and alloy steels with parts made from same.
In charge of booth: S. C. Spalding, H. J. Stagg, and Messrs. Galbraith, Atkinson, Schroeder, Talmadge, Kissam, Boland and Schnibbe.

R. G. Haskins Company, Chicago. Space S141 will exhibit:
Flexible shaft equipments, portable grinders, especially featuring those used so extensively in the drop forging industry for finishing dies, etc.
In charge of booth: R. G. Haskins, Ralph Sloan, C. C. Kendrick and Robert Spurgin.

Hauck Manufacturing Company, Brooklyn, N. Y. Space 18 will exhibit:
Hauck Venturi water-cooled open hearth oil burner with automatic triple cut-off valve and universal adjusting device; Hauck Venturi high pressure oil burners (air or steam) for continuous heating, plate heating, reverberatory melting and heat treating furnaces, also metal mixers. Hauck Venturi low pressure oil burners for heat treating, core ovens, enameling and melting furnaces, etc. Hauck Venturi flat flame oil burners for high pressure boilers, etc. Hauck oil ladle heaters; Hauck oil torches in different sizes for repairs to rolling mill machinery, open hearth furnace equipment, etc.
In charge of booth: F. A. Thomas, Pittsburgh representative; Herbert Vogelsang, Cleveland representative; and Jules Escheman, Buffalo representative.

Haynes Stellite Company, New York City. Space 51 with exhibit:
Haynes Stellite Tool Bits, and Welded Tools for turning, boring and planing; blades for milling cutters, boring bars, and reamers; solid milling cutters. Works rests for centerless grinders—dies—plug gages, fabric and rubber cutting knives—carpet cutter wires—linoleum mixing knives. Castings for valves, optical reflectors, die casting machine parts and hot billet scrapers.
In charge of booth: A. B. Leonard and W. J. Lindner.

Entrance to Highland Park.



Block House Lower Penn Avenue near Point Bridge. The oldest building in Pittsburgh, built in 1759, and the only historic relic of Pittsburgh's Colonial days. It is under the care of the Daughters of the American Revolution and open to visitors at all times.

Heppenstall Forge & Knife Company, Pittsburgh. Space 6-7-8 will exhibit:

Die Blocks, Shear knife, piston rod, nickel steel, chrome vanadium, samples of alloy steel, tinning roll, galvanizing roll and Ascoloy Steel.

In charge of booth: C. W. Heppenstall, Floyd Rose, J. A. Succop.

High Speed Hammer Company, Inc., Rochester, N. Y. Space S109 will exhibit:

Complete line of high speed riveting hammers and one drill press.

In charge of booth: H. A. Moore, C. W. Schuchardt, H. C. Levine and W. P. Andrus.

Hoover Steel Ball Company, Ann Arbor, Mich. Space S100 will exhibit:

One show case showing balls at different stages of production. This case may also contain bearings and valves illustrating the application of balls in industry.

One gaging machine showing how balls are separated for size. This machine will be able to separate balls which vary .0001 of an inch. Connected with this machine will be a small apparatus illustrating the uniformity of hardness of steel bars which are used in high grade bearings.

In charge of booth: Hilton G. Freeland, metallurgist and F. H. Lennox, sales manager.

Holcroft & Company, Detroit, Mich. Space S143 will exhibit:

Two of the latest type electric melting furnaces, one of which is specially adapted to laboratory use. Also, drawings, photographs, and technical data of our latest types of heat treating furnaces, also there will be shown drawings and photographs of open hearth steel furnaces, malleable reverberatory furnaces, with arrangements for burning both liquid and powdered fuel and all other types of furnaces used in the metallurgical industry.

In charge of booth: R. T. Cadwell, secretary and treasurer; H. L. Ritts, sales manager; C. E. Chaney, electrical engineer; J. T. Jans, mechanical engineer; H. M. Gregory and F. E. Gardiner, Canadian representatives.

Hoskins Mfg. Company, Detroit. Space 70 will exhibit:

An electrically heated tube furnace, so operated as to give individual heat treatment to the parts passing through it. Furnace is equipped with five tubes through which the material is pushed by an automatic pusher. The temperature is automatically controlled.

In charge of booth: Chas. S. Kinnison, James D. Sterling, W. D. Little and W. A. Gatward.

E. F. Houghton & Company, Philadelphia. Space 45 will exhibit:

Cutting Oils; Carburizers; Tempering and Drawing Oils; Vim Leather Belting and Vim Leather Packing.

In charge of booth: Herbert Lloyd, Chas. Schultz, Walter A. Buechner, David J. Richards and George W. Pressell.

Hunter Saw & Machine Company, Pittsburgh. Space S125 will exhibit:

Circular inserted tooth saws; circular solid tooth milling saws, suitable for Newton, Espen-Lucas, Higley, Lea-Simplex, Wagner, Cochrane-Bly, Nutter-Barnes, Burk, Smith & Post, Knowlton, Bryant and Q. & S. sawing machines. Hot saws, tube saws, friction disks,

Thaw Hall, University of Pittsburgh. The departments of Chemistry, Chemical Engineering with laboratories, and Engineering are lodged in this building.

Typical River Scene. Pittsburgh's River tonnage is greater than the world's four largest ports combined.

circular shear knives, slitter knives, skelp knives, pipe cutters, pneumatic hammer rivet sets and chisel blanks; brick mould liners, pattern core and molding plates; inserted tooth grinders for solid tooth saws, setting-up-device for setting teeth in inserted tooth saws. Circular knives for tobacco, cigarettes, cotton, cork, rubber, candy, paper, cloth, etc. Clutch disks, device for dressing friction disks, and many hardened steel specialties.

International Nickel Company, New York City. Space 37-46 will exhibit:

Samples of nickel steel and nickel steel products for various industrial uses.

In charge of booth: Paul D. Merica, Chas. McKnight Jr., Thos. H. Wickenden and L. Muller-Thym.

Interstate Iron & Steel Company, Chicago. Spaces 49-50 will exhibit:

Moving picture film entitled "The Story of Alloy Steel", two or three times daily in a room which has been provided adjacent to exposition room.

Also display of parts from Interstate steel and some typical test samples developed in their laboratory.

In charge of booth: W. J. MacKenzie, Elmer Larned, Paul Llewellyn and George Fisher.

Iron Age, New York City. Space 21 will exhibit:

The Iron Age.

In charge of booth: F. J. Frank, C. S. Baur, W. B. Robinson, D. C. Warren, H. E. Barr, B. L. Herman, C. Lundberg, E. Findley, E. S. Wayne, D. G. Gardner, C. L. Rice, E. Sinnock, F. Schultz, W. C. Sweetser, A. L. Marsh, O. B. Bergersen, W. W. Macon, E. T. Cone, G. L. Lacher, S. L. Prentiss and R. E. Miller.

Jones & Laughlin Steel Corporation, Pittsburgh. Space 26 will exhibit:

Cabinets, showing various products manufactured.

In charge of booth: J. J. Shuman, H. W. Graham and A. Milne.

Keller Mechanical Engineering Corp., Brooklyn, N. Y. Space 88 will exhibit:

Automatic Die Cutting machine, type F, fully electrically controlled, cutting a set of dies for Turbine Buckets as used in the most up to date machines. This machine can be operated fully automatically and by hand. All controls are centrally located and are push button control. This machine embodies some very revolutionary and novel features not shown heretofore in machine tools.

In charge of booth: S. A. Keller, Jules Dierckx, Henry Schreiber, Chas. Bitter and A. J. Benson.

King Refractories Company, Inc., New York City. Space 44 will exhibit:

"Flame Brand" high temperature cements for laying up fire brick settings; for veneering, patching, monolithic walls, rammed-in-linings, and insulating. "Mono" boiler baffling.

In charge of booth: S. C. Smith, president; E. J. Eddy, treasurer; and H. J. Parthesius, Pittsburgh representative.

Kinite Company, Milwaukee, Wis. Space S114 will exhibit:

Kinite dies as cast, Kinite dies machine finished, Kompite castings as cast, Kompite castings machine finished, Stampings made on Kinite and Kompite dies, Patterns from which dies have been made.

In charge of booth: E. J. Mohr, sales manager; T. A. Moormann, su-

perintendent; Wm. C. Eakin, representative for Pittsburgh and Ohio districts; H. F. Kluender, representative Michigan district.

Charles Kleist & Son, Jamestown, N. Y.—Space 40B will exhibit:
Drop Hammer Boards, built-up-type and standard type, Drop Hammer Pins.
In charge of booth: H. E. Kleist.

Laughlin-Barney Machinery Company, Pittsburgh. Spaces 57, 58, 59 and 60. The following firms will be represented in these booths: Ohio Machine Tool Co., Kenton, O., will occupy space 60 and will exhibit one 32-inch dreadnaught shaper. Oliver Instrument Co., Adrian, Mich., in space 59, will exhibit two automatic drillpointers and one die-making machine. Avey Drilling Machine Co., Cincinnati, O., space 59, will exhibit three drilling machines. Oilgear company, Milwaukee, Wis., space 58, will exhibit one 6-ton gooseneck broaching and assembling press. Laughlin-Barney Machinery Co. will occupy space 57, which will be used for reception purposes.
In charge of booths: C. C. Swift, Ohio Machine Tool Co.; E. C. Oliver, Oliver Instrument Co.; J. G. Hey, Avey Drilling Machine Co.; Howard Crull and W. D. Creider, Oilgear Co.; and the following will represent the Laughlin-Barney Machinery Co.: Harry Barney, John K. Henry, William Katzenmeyer, R. C. Neimeier, W. C. Pompey and J. M. Hill.

Leeds & Northrup Company, Philadelphia. Space 71-80 will exhibit:
Potentiometer Pyrometers, Indicating, Recording and Controlling, Optical Pyrometer, Hump Method for Heat Treatment; Equipment in full operation actually heat treating tools.
In charge of booth: G. W. Tall Jr., Henry Brewer, Oscar Brewer, E. B. Estabrook, Jordan Korp, A. E. Tarr, W. A. Lane and H. N. McMichael.

E. Leitz, Inc., New York City. Space S110 will exhibit:
Leitz Micro-metallograph; large metal microscope with camera; medium type metal microscope model "MO"; workshop microscope "MT"; Brinell microscope. Assortment of grinding and polishing machines. Several models of mineralogical microscopes. Assortment of accessories interesting to steel concerns.
In charge of booth: G. Spindler, in charge of technical department, and H. E. Bader, middle west representative.

Linde Air Products Company, New York City. Space S117 will exhibit:
Specimens, photomicrographs and macrographs of oxy-acetylene welds in various metals. The application of the oxy-acetylene process for various purposes and as used in the steel industries. Recent laboratory developments concerning the use and application of the process on steel products. A live exhibit of oxy-acetylene equipment. Welding and cutting apparatus equipment, etc.
In charge of booth: J. R. Dawson, Union Carbide & Carbon Research Laboratories, Inc., H. S. George, Union Carbide & Carbon Company, J. W. Foster, Linde Air Products Company and F. L. Rogers, Oxweld Acetylene Company and R. A. Sully, Linde Air Products Company.

Ludlum Steel Company, Watervliet, N. Y. Spaces 56-65 will exhibit:
Rustless Steel and Tool Steel.
In charge of booth: P. A. E. Armstrong, V. S. Yarnell.

Machinery, New York City. Space 40-A will exhibit:
Large wall screen showing interesting photograph covering "Heat

Treatment of Steel," Machinery, a mechanical journal covering the industries and a full line of Machinery's Mechanical Books.
In charge of booth: Erik Oberg, J. N. Wheeler and H. B. Hurlburt.

Mahr Manufacturing Company, Minneapolis,, Minn. Space 54, will exhibit:
Heat Treating Furnaces, blowers and kindred equipment. Mahrvel furnaces with a novel method of showing circulation will be on exhibition.
In charge of booth: H. A. Anderson, chief engineer, J. O. Connolly, sales department, home office, Benj. G. Harmon, Chicago branch manager and E. F. Piea, Philadelphia representative.

Jas. H. Matthews & Company, Pittsburgh. Space 2, will exhibit:
Marking Machines, Steel Stamping and Embossing Dies together with samples of products marked, brass dies for printing wooden boxes, rubber dies for printing corrugated boxes, identification badges, checks, tags and plates stamped and embossed, bronze signs, memorial and commemorative tablets.
In charge of booth: Mr. McConaghy, H. R. Wade and H. W. Ehrlen.

Midvale Company, Philadelphia. Space 81 will exhibit:
Complete line of products. Booth will also be used for reception purposes.
In charge of booth: Stuart Hazelwood and others.

Molybdenum Corporation of America, New York City. Space 27, will exhibit:
Various parts and products made from Molybdenum Steels such as springs, bearings, chisels, rolls, shovels, etc.
In charge of booth: J. M. Fuller, G. W. Sargent, president, J. W. Weitzenkorn, vice president and general manager, Clifton Taylor, general sales agent and E. A. Lucas, works manager.

Motch & Merryweather Machinery Company, Pittsburgh. Spaces 82 and 85 to 92 will exhibit:
In booths 85 to 92 and 82 across the aisle. There will be on exhibition in these booths various machinery from the following firms:

Gould & Eberhardt, Newark, N. J.	85
Blanchard Machine Co., Cambridge, Mass.	85
Giddings and Lewis Machine Tool Co., Fond du Lac, Wis.	86
V & O Press Co., Hudson, N. Y.	86
Bullard Machine Tool Co., Bridgeport, Conn.	87
Keller Mechanical Engineering Corp., Brooklyn	88
Motch & Merryweather Office	89
Baker Bros., Toledo, Ohio	89
Cincinnati Milling Machine Co., Cincinnati, O.	90
Cincinnati Grinding Co., Cincinnati, Ohio	90
National Automatic Tool Co., Richmond, Ind.	91
American Tool Works Co., Cincinnati, Ohio	92

In charge of booths: E. C. Batchelar, manager, J. T. McCuen, J. A. Menges, L. A. Rafferty, L. C. Deckard and J. L. Vance.

National Automatic Tool Company, Richmond, Ind. Space 91, will exhibit:
Natco Multi Drilling machines, Natco Multi Tapping machines, Natco Universal points, Natco Drill holders, Natco Tap Holders and Natco Quick change holders.
In charge of booth: Edward D. Frank, Ray Sterling and R. N. Piper.

National Machinery Company, Tiffin, Ohio. Space 12.
This company will have reception space.
In charge of booth: E. R. Frost, F. J. Mawby, K. L. Ernst and Chas. D. Harmon.

National Twist Drill & Tool Company, Detroit. Space S136 will exhibit:
Complete line of products.
In charge of booth: H. K. Chambers, assistant secretary.

R. D. Nuttall Company, Pittsburgh. Space S113, will exhibit:
B P tough hard gears and pinions of the spur and helical type. Fractured sample teeth of our different hardened grades of gears. Flexible couplings, and miscellaneous industrial gears.
In charge of booth: O. W. Hershey, sales manager, Milton Rupert, vice president, W. H. Phillips, manager of engineering, J. E. Mullen, assistant sales manager; C. H. Parker, R. R. Gartside, W. H. Smith and R. W. Young.

S. Obermayer Company, Chicago. Space 63, will exhibit:
Refractory furnace cements and refractories as well as various charcoals, graphite and also description of the application of various refractories to furnace construction.
In charge of booth: J. L. Cummings, manager, refractory division; E. D. Frohman, vice president; F. P. Bullion, Pittsburg office; and Mr. Eggert, salesman.

Ohio Machine Tool Company, Kenton, Ohio. Space 60, will exhibit:
One 32-inch "Ohio" dreadnaught shaper.
In charge of booth: C. C. Swift, manager; and Louis Peters, superintendent.

Ohio Steel Foundry Company, Springfield, Ohio. Space 15 will exhibit:
Fahrite—Alloys and Equipment.
In charge of booth: H. G. Shook.

Oilgear Company, Milwaukee, Wis. Space 58 will exhibit:
One 6-ton new gooseneck broaching and assembling press, type PJ. with automatic control. This machine will be in operation and will be driven by a 5-horsepower constant speed motor.
In charge of booth: Howard Crull and W. D. Creider.

Oliver Instrument Company, Adrian, Mich. Space 58, will exhibit:
Two Oliver of Adrian automatic drillpointers, and one Oliver of Adrian die making machine.
In charge of booth: W. G. Schutt and E. C. Oliver.

Pangborn Corporation, Hagerstown, Md. Space 74-75-83-84, will exhibit:
Barrel Sand-Blast, Cabinet Sand-Blast and Rotary Table Sand-Blasts all of which will be in operation demonstrating the sand-blasting of heat-treated parts, forgings, etc.
Display of photographs illustrating sand-blast installation in heat treating plants, interesting specimens of heat treating art and complete display of metallic abrasives.
Angular Steel Grit and Samson Steel Shot, with data and information in regard to their use.
In charge of booth: John C. Pangborn, vice president; H. D. Gates, sales manager and F. E. Wolf, district sales engineer.

Pannier Bros. Stamp Company, Pittsburgh. Space S126, will exhibit:
Steel Stamps, Steel Stamping dies, Steel Embossing dies; Terne Plate dies, Metal shipping tag addresser, Pipe tag marking machine, Embossing numbering machine, marking equipment for Sheets, Plates and Structural materials including rubber dies and holders, interchangeable rubber type and holders and rubber heat stamps.
In charge of booth: O. M. Pannier, president; W. J. Pannier Jr., vice president; F. Speicher Jr., superintendent; W. W. Hague, business manager; and C. C. Gray, manager of sales.

Park Chemical Company, Detroit. Space S108, will exhibit :
Complete line of heat treating materials consisting of: case hardening compounds, cyanides, cyanide mixtures, reheating—lead pot carbon, quenching and drawing oil, furnace cements, etc.
In charge of booth: N. S. Schermer and J. N. Bourg.

Peerless Machine Company, Racine, Wis. Space S135 will exhibit.
One Peerless high-speed hack saw; one Peerless Universal shaping saw—sizes 6 x 6″; and one Peerless Universal shaping saw—size 13 x 13″. All of these saws are motor driven.
In charge of booth: H. J. Swanson, general sales manager; A. H. Goetz, Pittsburgh representative; and R. W. Hansen, Cleveland representative.

Penton Publishing Company, Cleveland. Space 73, will exhibit:
Technical books and periodicals.
In charge of booth: J. D. Pease, advertising manager; John Henry, advertising department; E. F. Ross and C. J. Stark, editors; F. V. Cole, circulation manager; S. Frank, salesman; and S. H. Jasper, Pittsburgh manager.

Pennsylvania Pump & Compressor Company, Easton, Pa. Space 92A will exhibit:
Machine supplying air for Pangborn Corporation exhibit.
In charge of booth: Ward Raymond, vice president.

Pittsburgh Crucible Steel Company, Pittsburgh. Space S120 will exhibit:
Complete line of steel manufactured.
In charge of booth: F. B. Hufnagel.

Pittsburgh Instrument & Machine Co., Pittsburgh. Space S124, will exhibit:
Brinell testing machines; impact testing machines; metal sheet tester; metallographic grinding machine; instruments for measuring Brinell impressions and weight calculating instrument.
In charge of booth: Paul Kammerer and Charles Trueg.

Quigley Furnace Specialties Company, New York City. Space 61, will exhibit:
Hytempite, (high temperature cement)—its application in building and repairing furnace walls. Quigley insulating brick for reducing heat losses in furnace structures.
In charge of booth: W. H. Gaylord Jr. and D. F. McMahon.

Racine Tool & Machine Company, Racine, Wis. Space S140, will exhibit:
No. 5 Racine High-Speed Metal Cutting machine 6″ capacity, motor driven, Racine Junior metal cutting machine, motor driven 4″ capacity, Racine Duplex band saw for cutting all wood, soft metals and hard metals complete with two-speed transmission and gravity feed vise motor driven.

In charge of booth: M. E. Erskine, president; D. B. Maxwell, salesman and R. E. Fuller, mechanic.

W. S. Rockwell Company, New York City. Space 24 will exhibit:
Models of operating furnaces.
In charge of booth: J. N. Voltmann and C. D. Barnhart.

Rodman Chemical Company, Verona, Pa. Space 20, will exhibit:
Case Hardening materials, Luting materials, Quenching oils and Tempering oils.
In charge of booth: Hugh Rodman, general manager; and Gordon A. Webb, Detroit district manager.

Roessler & Hasslacher Chemical Company, New York City. Space S131 will exhibit:
Chemicals: Sodium Cyanide, Roessler & Hasslacher Hardener, Granular (96-98 per cent); Granular (73-76 per cent); Cyanegg (73-76 per cent); Block (73-75 per cent); Copper Cyanide; Zinc; Sodium Prussiate; Potassium Prussiate; Soda Ash; Caustic Soda.
Case Hardened gears, pinions, etc.
In charge of booth: C. H. Proctor, metallurgical and plating expert; Wm. M. Gager, metallurgical expert, and a Pittsburgh representative from sales office.

F. J. Ryan & Co., Philadelphia. Space S132, will exhibit:
Different types of burners; model of new pattern sectional furnace construction; automatic control for high and low pressure burners. Enlarged photos of type of installations.
In charge of booth: J. L. Edwards, manager, Pittsburgh office; F. A. Hall, sales department, Philadelphia office; G. F. Beach, chief engineer, Philadelphia office; and F. J. Ryan, president, Philadelphia.

Scientific Materials Company, Pittsburgh. Space S128, will exhibit:
Brinell machine; F. & F. optical pyrometer; Scientific Materials Company's optical bench; polishing and grinding machines; levigated alumina.
In charge of booth: E. H. Fisher, E. C. Mateja and E. P. Dillinger.

Shore Instrument & Mfg. Co., Jamaica, N. Y. Space S133, will exhibit:
Latest improved C-type Scleroscope (bulb type). Latest improved model "D" recorder (Dial type). These instruments are for the testing of hardness of metals. A and B type Pyroscope—optical temperature indicators from 1200 Fahr. to 3000 Fahr. Elastometer and Durometer—testing plastic materials as rubber. Localcase is used in carburizing and Localhard is used for Tool Steel—also various fixtures for holding work while testing.
In charge of booth: F. G. Kendall and assistant.

The Spencer Turbine Company, Hartford, Conn. Space 95, will exhibit:
Catalogue No. 1515 turbo compressor; Catalogue No. 1505 turbo compressor and catalouge No. 1001 turbo compressor as used for supplying air in connection with oil or gas burning industrial furnaces, foundry cupolas, etc.
In charge of booth: H. M. Grossman, sales engineer; and O. J. Dingee, engineer.

Steel City Testing Laboratories, Pittsburgh. Space S150, will exhibit:
Latest Model Brinell Machines.
In charge of booth: H. A. Weaver.

Surface Combustion Company, New York City. Space 17, will exhibit:
Surface Combustion products as follows: low pressure air-gas inspirator; high pressure air-gas inspirator; velocity burner; impact and tunnel burners; combination oil and gas burner.
In charge of booth: F. J. Winder and W. M. Hepburn.

Tacony Steel Company, Philadelphia. Space 48, will exhibit:
Alloy bar steel, forgings, die blocks, piston rods and trimmer steel.
In charge of booth: H. A. Baxter, general manager of sales; C. W. Forcier, Pittsburgh district sales manager.

Tate-Jones & Company, Inc., Pittsburgh. Space S129, will exhibit:
Oil and gas burners. Automatic control apparatus for oil and gas furnaces; automatic electric heat treating furnace information; continuous oil, gas and coal fired heat treating furnace information. Standard annealing, hardening, heat treating and forging furnace information.
In charge of booth: L. C. Jacobus, sales manager; L. S. Kelso, and H. E. Marks, Pittsburgh district representatives; Edward Busch, Detroit district representative; James H. Knapp, Los Angeles district representative; P. J. Myall and J. L. Stroman, Chicago district representatives; W. M. Smith, New York district representative; and George Ellerton, Pittsburgh office.

Taylor Instrument Company, Rochester, N. Y. Space 34 will exhibit:
The exhibit will consist of portable and stationary type electrical pyrometers both indicating and recording also including a full line of heavy duty and high temperature thermocouples. Also thermometers for oil, brine and lead tempering baths, electrical controls, solenoid valves, recording thermometers and pressure gages.
In charge of booth: E. C. Taylor, Pittsburgh; Avery Taylor, Pittsburgh and G. A. Howell, Rochester, N. Y.

Tinius Olsen Testing Machine Company, Philadelphia. Space 72 will exhibit:
One small Universal Testing Machine. Also attachments for Brinell Hardness, Ductility of Sheet Metal, and for testing welds of welding material. Also various Ductility Testing Machines.
Impact or Repeated Impact Testing Machines, an Elasticity Testing Machine for wire, various instruments, such as Extensometers and Strain Gages and also various types of Hardness Testers to include the Olsen Hydraulic Brinell Hardness Testers, the Olsen Last Word Hardness Testers of two sizes and also a number of the New Herbert Pendulum Hardness Testers, which will be exhibited for the first time in the United States. Edward G. Herbert himself expects to take a trip over to this country and attend the convention and exposition in Pittsburgh and will have his headquarters at this booth during that time.
One of the latest Olsen-Carwen Static-Dynamic Balancing Machines with all the latest improvements for testing rotating parts as is now used by many of the large motor and automobile manufacturers throughout the country.
In charge of booth: R. B. Lewis, Tinius Olsen, T. Y. Olsen, and Edward G. Herbert, Manchester, England.

Union Electric Steel Corporation, Carnegie, Pa. Space 55 will exhibit:
Die Blocks, Piston Rods, Rams and Trimmer Steel.
In charge of booth: W. L. Goodrich, Ross J. Emery, David Stuart, I. J. Johnson, W. H. Rieger and R. E. Lee.

United Alloy Steel Company, Canton, Ohio. Space 10-11 will exhibit:
Automotive parts and industrial parts made from alloy steel.
In charge of booth: H. H. Pleasance, vice president; W. H. Wiewel, assistant manager of sales; M. F. McOmber, district sales agent; and F. W. Krebs, sales engineer.

United States Chain & Forging Co., Pittsburgh: Space S134 will exhibit:
A display of heat treated and tested chain showing the advantages

of heat treatment over the untreated chain.
In charge of booth: Frank A. Bond, Frank L. Campbell, W. G. Hardy and William H. Reid.

The V & O Press Company, Hudson, N. Y. Space 86 will exhibit:
V & O Double Length Slide Inclinable Power Press; a model of our Press Clutch; a set of parts for a Standard Press; various sample boards, photographs, etc.
In charge of booth: Edward Cairns and R. O. Brunst.

Vanadium-Alloys Steel Company, Latrobe, Pa. Space 29-30 will exhibit:
Tool steels treated in different ways; tool steel fractures. Various tools showing uses of tool steels. Products made from tools made of tool steel.
In charge of booth: A. F. Chilcott, Buffalo; W. R. Mau, A. G. Henry, and R. F. Noonan, all of Chicago; F. W. Potts, Cincinnati; J. H. Caler, R. L. Daull and T. J. Van de Motter, all of Cleveland; J. S. Cole, Dayton; A. F. McFarland, Dearborn; D. D. Dodd, Detroit; D. A. Black and L. G. Murray of Dorchester, Mass.; E. B. Kitfield, Wallingford, Conn.; J. A. McKay, Jersey City, N. J.; A. W. Stephenson, Philadelphia; F. C. Comas, Reading; H. P. Edison and R. R. Artz of Pittsburgh; D. L. Bardes, McKees Rocks, Pa.; and W. S. Dunlay, St. Louis.

Vanadium Corporation of America, New York City. Space 16-25 will exhibit:
Specimens of Vanadium ore and Ferro Vanadium.
In charge of booth: Colonel M. G. Baker, vice president; B. D. Saklatwalla, general manager; Geo. L. Norris, C. F. Fritz, J. A. Miller, Jr., Walter Flannery and H. T. Chandler.

Vulcan Crucible Steel Company, Aliquippa, Pa. Space S127 will exhibit:
Tool Steels (high speed, alloy and carbon); special steels and materials used in their manufacture and tools and parts made from them.
In charge of booth: G. L. Kronfeld and A. D. Beeken Jr.

Warner & Swasey Company, Cleveland. Space S118 will exhibit:
2 A Universal hollow hexagon turret lathes. The design of this machine makes it readily adaptable for machining both bar and chucking work and these features will be demonstrated.
In charge of booth: A. C. Cook, general sales manager; C. J. Stilwell, domestic sales manager; A. H. Keetch, district manager of Buffalo and Pittsburgh territories; J. E. Figner, district representative, Pittsburgh; and E. Kunze, demonstrator.

Westinghouse Electric & Mfg. Co., East Pittsburgh. Space 77-78 will exhibit:
Four muffle furnaces with control features: Type B-36, Type B-14, Type B-12, Type L-5-12. One, Type R-14 crucible furnace, One, Type K-10 oven, Two, low-temperature melting pots, One, small combustion tube furnace, One, small solder pot; two, Type C over heaters; one, air heater, and eight, space heaters.

Wilson-Maeulen Company, New York City. Spaces S138-139 will exhibit:
Pyrometers, Rockwell Hardness Testers.
In charge of booth: S. C. Horn, C. E. Hellenberg and Harvey Lee.

Witherow Steel Company, Pittsburgh, Pa. Space 39 will exhibit:
Continuous die rolled products consisting of rolled sections, front axles, ring gears and rear axle drive shafts.
In charge of booth: W. P. Witherow, president; J. S. Langston, general sales manager; W. C. Emory, assistant sales manager; and L. Leibinger, sales engineer.

THE HARDENING OF STEEL

By Zay Jeffries and R. S. Archer

Abstract

In this paper there are given a general definition of hardness, a brief statement of a general theory of the hardening of metals, and a detailed conception of the nature of hardened steel and of the causes for its hardness. Martensite is considered to owe its hardness chiefly to the very small grain size of the Alpha iron of which it is composed. Aging or mild tempering causes a precipitation of very fine particles of cementite which constitute an additional hardening factor. The softening of hardened steel by tempering is due to the growth of the Alpha iron grains and of the cementite particles.

THE nature of hardened steel and the cause of its hardness were for many years among the chief subjects of metallurgical investigation and discussion. A point was finally reached when it appeared that further theoretical discussion was nothing more than idle speculation because of the lack of sufficient fact evidence. In 1915, Sauveur made the following statements as a conclusion to a paper on "Metallography and the Hardening of Steel."

"It will be obvious from the foregoing that the many recent attempts at arriving at a satisfactory explanation of the hardening of steel are based on one or more of the following conceptions: (1) existence of a hard allotropic variety of iron, (2) existence of solid solutions involving the occurrence of so-called "hardening" carbon, and (3) existence of strains in quenched steel causing or not an amorphous condition of the iron.

"It will likewise be obvious that no theory so far presented fully satisfies our craving for a scientifically acceptable explanation of the many phenomena involved.

"It would seem as if the methods used to date for the elucida-

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A paper to be presented before the annual convention of the Society, Pittsburgh, Oct. 8-12, 1923. The authors are associated with the Research Bureau of the Aluminum Co. of America, Cleveland. Written discussion of this paper is invited.

tion of this complex problem have yielded all they are capable of yielding and that further straining of these methods will only serve to confuse the issue, a point having been reached when this juggling, no matter how skillfully done, with allotropy, solid solutions, and strains is causing weariness without advancing the solution of the problem. The tendency of late has been to abandon the safer road of experimental facts and to enter the maze of excessive speculations, in which there is great danger of some becoming hopelessly lost.

"The conclusion seems warranted that new avenues of approach must be found if we are ever to obtain a correct answer to this apparent enigma."

For a number of years there has been a lull in the discussion of this subject. Recently there has become available additional experimental evidence bearing on the constitution of hardened steel, so that it now appears profitable to resume the consideration of the cause or causes of its hardness.

The authors have had occasion to make a careful analysis of the various properties of metals and alloys, and to develop a general theory of hardening. This was published under the title "The Slip Intefrerence Theory of the Hardening of Metals" in the June 15, 1921 issue of *Chemical & Metallurgical Engineering*. In the latter part of that article the hardness of steel was considered as a special application of this general theory. Since that time there has been much discussion of the views put forth and some additional evidence has accumulated. It is the purpose of this paper to summarize the evidence bearing on the nature of hardened steel and to present the views of the authors regarding the causes of hardness in the light of all evidence available up to date. As a preliminary to the discussion of steel, there will be given a brief statement of the general theory of hardness.

Definition of Hardness

The general terms "hardness" and "strength" connote a number of more specific physical properties. The most definite of these is the proportional limit or, what is practically the same thing, the elastic limit. The common measure of the strength of a material is its "tensile strength," or the maximum intensity of tensile stress endured before rupture, calculated on the original cross-sectional

area of the test-piece. This is obviously a more complex property than the elastic limit. Hardness may mean resistance to indentation, as measured by the Brinell test, resilience, as measured by the Shore scleroscope, scratch hardness, cutting hardness, resistance to machining, or some other special kind of hardness. All of these properties may be embraced in the general definition: *Hardness is resistance to permanent deformation.*

Fundamental Cause of Hardness

Metals owe their resistance to deformation to the forces between the atoms. These forces are both attractive and repulsive. Repulsive forces are manifested by the resistance of metals to hydrostatic pressure by which the atoms are forced closer together in all directions. Under ordinary compression loading, the atoms are forced together in the direction of the compression but apart in the direction of the secondary tensile stresses. Under direct tension the distances between atoms are increased in the direction of the load and decreased at right angles, that is in the direction of the secondary compressive stresses. There is no condition of loading corresponding to a negative hydrostatic pressure, under which the interatomic distances would be increased in all directions.

Any permanent deformation of a metal involves changes in the relative positions of some of the atoms, and, therefore, the breaking, temporarily at least, of some interatomic "bonds." The rupture of any material, whether with or without permanent deformation, also involves the breaking of interatomic bonds. The greatest possible resistance that a material can offer to deformation or rupture is the summation of all the interatomic bonds on a plane through the specimen normal to the stress, a summation which may for convenience be termed the "absolute cohesion" of the material. Actually such a summation of forces is never realized, because rupture always takes place by degrees, and the breaking of atomic bonds is not simultaneous. The tensile strength of a material merely represents the maximum number of atomic bonds that come into play simultaneously during the test.

Great Inherent Cohesion of Metals

Absolute cohesions of metals are far in excess of the values

obtained for tensile strength. A qualitative illustration of this fact may be found in a consideration of some properties of pure iron. The tensile strength, after hot-rolling, is about 40,000 pounds per square inch, a value representing as usual the maximum load divided by original cross-section. If the actual reduced area of the test-piece is measured throughout the progress of the test and the stress computed on this basis, a value will be found for the maximum stress which is much higher than the tensile strength. The maximum stress will then be about 80,000 pounds per square inch. Severely cold-worked iron may show a tensile strength of 150,000 pounds per square inch. The maximum actual stress is again somewhat higher (165,000), but not in so large a ratio as in the case of the hot-rolled iron. Even in the cold-worked iron, rupture still takes place by degrees—that is, by a kind of tearing action—so that the highest of these figures still does not represent the inherent absolute cohesion.

Some very interesting tests of glass have been reported by Griffith[1]. In ordinary fibers of 0.040-inch diameter the material had a tensile strength of about 25,000 pounds per square inch. The tensile strength was found to increase as the diameter of the fibers decreased, and in very fine fibers, carefully prepared, surprisingly high values were obtained. The maximum strength recorded was 498,000 pounds per square inch at a diameter of 0.00016 inch. Plotting the reciprocal of the tensile strength against the diameter of the fiber and extrapolating to zero diameter, Griffith found a value of 1,600,000 pounds per square inch representing the theoretical "absolute cohesion" of the glass.

Calculations based on the energy required to separate the atoms of metals by vaporization give values up to about 5,000,000 pounds per square inch for the "intrinsic pressure," a quantity which is theoretically of the same order of magnitude as the absolute cohesion.

The accuracy of Griffith's extrapolation and of values for cohesion derived from the heat of vaporization may be questioned. The actual numerical values reached are of little significance. The important thing is that metals possess very great inherent cohesion, greater probably than is ever realized in tensile tests of

1. The Phenomena of Rupture and Flow in Solids. A. A. Griffith. *Philosophical Transactions*, Series A, Vol. 221, pp. 163-198.

the pure metals or their strongest alloys. Looked at from this point of view, the problem of the hardening and strengthening of metals by various means becomes more simple. Instead of inquiring why metals are so strong, we may better ask why metals are so weak.

Hardening Due to Slip Interference

Metals are crystalline and are built up of atoms arranged in definite and repeating patterns. The regularity of atomic arrangement gives rise to certain planes of weakness, or low resistance to shearing stress. When an external load produces a shearing stress on such a plane which exceeds the resistance of the crystal to shear on that particular plane, fracture of the crystal takes place. The fragments formed may or may not adhere to each other. If they do not, the failure of the crystal is complete, and it is said to be brittle. The plane of weakness is then known as a cleavage plane. More generally, in the useful metals, the crystal fragments adhere and merely glide or "slip" over each other. The result of such slip, repeated on many planes, is a measurable permanent deformation, the crystal is ductile, and the planes of weakness are called "slip planes."

The first appreciable formation of slip planes marks the beginning of plastic deformation and therefore the passing of the elastic limit. The resistance to permanent deformation, which is a general measure of hardness and strength, represents resistance to the beginning and propagation of slip. Anything that serves to hinder slip is a source of strength and hardness. *The hardening and strengthening of metals by any of the known methods may be considered as due principally to interference with slip.*

Hardening Effect of Grain Refinement

In an aggregate of many grains of different orientation, there cannot be any continuous plane of weakness. The application of a load cannot produce any slip planes extending entirely across the section, as in the case of a single grain. When slip takes place in any one grain it cannot continue without change of direction into adjacent grains because, except in very rare instances, the potential slip planes of adjacent grains do not register. The

permanent deformation of the metal is thus resisted at the grain boundaries by the disregistry of the planes of low cohesion, and, especially in fine-grained metals, by the specific hardness of the amorphous cement, which hardness itself is due to the absence of planes of weakness. The result is an increase in elastic limit, hardness, and strength.

Hardening by Cold Working

The permanent deformation of a metal by cold-work involves the breaking of the grains into fragments along intersecting systems of slip planes, and movement of these fragments with respect to each other. In the first stages of deformation the crystalline fragments within any one grain undoubtedly retain considerable uniformity of orientation. As the deformation proceeds, there must be some rotational movement of the fragments, this being especially true near the old grain boundaries. Insofar as new orientations are created, the effect is equivalent to grain refinement. It is probable that even after severe cold-working there is still general uniformity of orientation in the fragments of any particular grain. The slip interference at the surfaces between such fragments of somewhat similar orientation is, therefore, more on the order of the interference at twinning planes than of the interference at grain boundaries. Additional interference is offered by such amorphous metal layers as may be formed at the slip planes.

Nature of Solid Solutions

It is a general rule that metals are hardened and strengthened by the addition of elements which dissolve in them to form solid solutions. Our knowledge of the structure of solid solutions is quite limited, but from the results so far obtained it seems that the atoms of the solute replace those of the solvent without substantial change in the space lattice of the latter, up to the limit of the first or "Alpha" solution in case of limited solubility, or the first of a series of solid solutions. This conclusion is based upon studies of alloy series in which the components have similar atomic volumes, and somewhat different conditions may obtain when this criterion is violated. There is good reason to believe, however,

that in all cases solid solutions are characterized by the *atomic* dispersion of their components.

Condition of Compounds in Solution

When an intermetallic compound forms and dissolves in one of the component metals, it is commonly considered to go into solution "as such." For example, austenite has been generally held to be a solution in "Gamma" iron of iron carbide rather than of elementary carbon. This implies that distinct molecules of iron carbide are dispersed in the Gamma iron.

From the evidence available, and particularly from a consideration of the phenomena of diffusion, the authors have reached the conclusion that this is not the case, but that the carbon in austenite is present as individual atoms of carbon. These atoms are undoubtedly held strongly to the neighboring iron atoms, but the union is not permanent. Diffusion must consist in a migration of carbon atoms and not of groups or "molecules" containing several iron atoms. Such groups could not, on account of their size, diffuse through solid iron.

According to this view cementite has no existence except as a crystalline substance, which is not merely precipitated but *formed* on the decomposition of austenite.

Hardness of Solid Solutions

The increased hardness and strength of solid solutions are traceable directly to increased interatomic forces, the attraction between unlike atoms being in general greater than between like atoms. We may conceive an additional mechanical factor in the form of a roughening of the slip planes due to the presence of atoms of unlike size, or, as Bridgman puts it, a staggered arrangement of the atoms. The hardening and strengthening effects of grain refinement and cold-working apply to solid solutions as well as to pure metals, and are superimposed upon the hardening effect of the solute.

Metallic Compounds

The structural constituents in alloys which possess the greatest specific hardness and strength are the intermetallic compounds

and nonmetallic compounds such as oxides. In general, these compounds are of a low order of symmetry, which, together with the large interatomic forces involved, accounts for their great hardness. The atoms are probably arranged in such a way that those of one element are not interchangeable with those of another element. This would account for their lack of plasticity.

One of the most important considerations in the loading of any brittle material is eccentrically distributed stress. A ductile material subjected to eccentric loading quickly adjusts itself by permanent deformation at any points where the stress exceeds the elastic limit, with comparatively little damage. This is not possible in a brittle substance, and if the stress at any point in a piece subjected to load exceeds the elastic limit, rupture results. It is obviously easier to avoid local overstressing in small pieces than in large pieces. This accounts for the fact that many materials, which are commonly thought of as very fragile, show remarkably high strength when tested in small sections. Vitreous silica, for example, is quite easily broken when in fairly large pieces, although it shows a tensile strength as high as 160,000 pounds per square inch in the form of fibers.

This point is important in the present discussion in connection with intermetallic compounds. These substances are as a rule hard and brittle, and are too commonly considered to be weak. Their true strength when properly protected against eccentric loading by their small size and by imbedding in a ductile matrix is undoubtedly very high. We may safely assume that cementite, for example, has a strength of several hundred thousand pounds per square inch.

The Obstruction Principle

It has long been recognized that the presence of a hard and strong constituent in an alloy may strengthen it by opposing the "flow," or slip, or the weaker constituent. Just as slip is opposed at the grain boundaries of a pure metal by the change in orientation, it may be opposed to a still greater extent if the material at the grain boundary possesses in addition to its different orientation a specifically greater hardness. The most familiar example of this is the reinforcing effect of the pearlite constituent in hypoeutectoid

steels. While pearlite is not a single constituent, it may well be imagined to have an effect like that exerted by hypothetical similar grains of a strong solid solution. The structurally free ferrite is the continuous phase, in which the pearlite is scattered as disconnected islands. If the free ferrite were a structureless amorphous substance, the pearlite could produce only a mild strengthening effect, by a sort of frictional resistance to flow, but the ferrite is crystalline and yields only by slipping on its crystallographic planes of weakness, and such slip is opposed by the rigidity of the pearlite.

This mechanism of hardening, which has been described as the "obstruction principle,"[2] refers particularly to reinforcement of a continuous ductile matrix by grains of a stronger constituent which are similar in size to the grains of the matrix. The grains of the matrix are strengthened by *external* support.

Hardening by Particles Within Grains

Metals can be hardened to a still greater degree by a hard substance in the form of small particles dispersed *within* the grains. A familiar example of this hardening action is found in granular pearlite. A steel containing 0.90 per cent carbon in the form of small round particles of cementite having an average diameter on the order of 0.0001 inch has a Brinell hardness of about 170 as compared with a hardness of about 80 for the ferrite matrix when free from carbon.

The ability of disconnected particles of a hard substance to harden a matrix is dependent on the crystalline structure of that matrix. The ferrite matrix in the steel just mentioned is soft because of the presence of many planes of weakness. The cementite particles scattered through this matrix harden it by interfering with slip along these planes. The particles may be considered to act as *keys* mechanically obstructing any motion along the planes of weakness. The result is increased elastic limit, hardness and strength.

The hardening effect of a given amount of hard material thus dispersed within the grains of a ductile crystalline matrix is

2. The Metallography of Steel and Cast Iron. Henry M. Howe.

very largely dependent on the size of the particles. Troostite consists of particles of cementite of submicroscopic size dispersed in ferrite. A steel containing 0.90 per cent carbon in the troostitic condition has a Brinell hardness around 400 or 500. This greatly increased hardness as compared to granular pearlite is due partly to the much smaller size of the cementite particles and partly to the smaller size of the grains of the ferrite matrix.

The effect of particle size is masked in the case of steel by accompanying changes in the grain size of the matrix. The principles are shown more clearly in certain aluminum alloys in which the size of the hard dispersed particles can be varied through a wide range without any change in the grain size of the matrix. From a study of these alloys it appears that the hardness increases as the particle size decreases but that a particle size is finally reached which produces maximum hardness. Smaller particles have somewhat less hardening effect.

The average size of particle which produces maximum hardness has been referred to as the *critical* size and the hard substance is said to be in a condition of critical dispersion.

Grain Refinement in Iron at A3 Point

When pure iron is heated above 900 degrees Cent. (1652 degrees Fahr.) so as to cause the A3 allotropic change to take place, there occurs a complete change in its crystalline structure. The body-centered cubic lattice of the Alpha iron changes to the face-centered cubic lattice of Gamma iron. There is a contraction of volume on the order of 1.5 per cent when Alpha iron changes to Gamma iron. The grains of Gamma iron form from many centers or nuclei which are usually at the grain boundaries of the Alpha iron. The grain boundaries of the Gamma iron do not coincide with old grain boundaries of the Alpha iron. In other words, the transformation of Alpha to Gamma iron not only represents a change in space lattice, but also the entire disappearance of the Alpha grains and the birth of new Gamma iron grains whose size and shape are determined by the ordinary conditions affecting grain growth. The A3 transformation point is in a temperature range of grain growth for both Alpha and Gamma iron.

When Gamma iron is cooled through the A3 point so as to form Alpha iron an entirely new set of Alpha iron grains is formed. The formation of Alpha iron involves an expansion (about 1.5 per cent in volume) of the same magnitude as the contraction when Alpha changes to Gamma iron. The new Alpha grains begin to form at the grain boundaries of the Gamma iron. The size and shape of the new Alpha grains will depend largely on the conditions obtaining during and after the transformation. Slow cooling allows time for growth of the Alpha grains and favors the formation of relatively few nuclei. Rapid cooling, as for example water quenching from above A3, promotes the formation of more nuclei and retards grain growth after the transformation is complete.[3]

Pure Iron Not Hardened by Quenching

Samples of Armco iron containing about 0.02 per cent carbon showed about seven (7) times as many grains per unit volume when quenched from 1300 degrees Cent. (2372 degrees Fahr.) as when furnace cooled from the same temperature. This reduction in grain size is slight and the change in properties between quenched and furnace-cooled Armco iron is correspondingly small. It does not seem possible to greatly affect the grain size of pure iron by rapid cooling through the A3 transformation point. Pure iron has been referred to, therefore, as incapable of being hardened by quenching from above the so-called upper critical temperature, which is the A3 point. It is probable that the lowering of the transformation temperature of Gamma iron to Alpha iron at Ar_3 by rapid cooling is very slight. The heat evolved and the relatively high temperature of the transformation, coupled with the low thermal conductivity of iron, seems to allow pure iron during quenching sufficient time in which to form relatively large grains of Alpha iron.

Hardening of Iron-Nickel Alloys by Quenching

When pure nickel is added to pure iron the A3 transformation of the alloy is progressively lowered from about 900 degrees Cent. (1652 degrees Fahr.) to room temperature as the nickel

3. Grain Size Inheritance in Iron and Carbon Steel. Zay Jeffries, *Transactions* A. I. M. E. 1918, Vol. 58, page 669.

content is increased from zero to about 25 per cent. On rapid cooling from a high temperature, samples containing 85 per cent iron and 15 per cent nickel can be obtained at room temperature in the Gamma or austenitic condition. If cooling takes place at such a rate as to allow the Gamma-Alpha change to occur, the grain size of the transformed alloy becomes smaller as the temperature of Ar_3 is lowered, because the low temperature of transformation produces undercooling and hence favors the formation of many nuceli and defeats grain growth.

There is very little information regarding the mechanical properties of pure iron-nickel alloys having a nickel content up to 25 per cent. Much work, however, has been done on iron-nickel alloys containing small amounts of carbon. An iron-nickel alloy containing 7.54 per cent nickel, 0.09 per cent carbon, and 0.04 per cent manganese, had its strength doubled by quenching from a dull red heat. A steel of the same composition but without nickel shows very little change in physical properties after such a quenching.[4] Edwards concludes from a general review of the work on iron-nickel alloys that the presence of carbon is not necessary in order for hardening to take place on quenching.

The hardness of these iron-nickel alloys in the fine-grained condition is partly accounted for by the nickel in solid solution in the iron, but is due chiefly to the marked refinement of grain. When nickel is added to iron, only the A3 transformation is affected and this may be lowered to any desired temperature below 900 degrees Cent. (1650 degrees Fahr.) and with sufficient nickel the transformation does not take place at all. At the A3 point in iron-nickel alloys there is only the Gamma to Alpha transformation to take place and if this takes place at a sufficiently low temperature the Alpha modification will be fine grained and consequently relatively hard and strong.

The Allotropic Transformation in Iron-Carbon Alloys

Likewise, when carbon is added to iron, the A3 transformation is lowered, but with more than about 0.05 per cent carbon the transformation is not a simple one as in the case of iron-nickel alloys but is composite, yielding under equilibrium condi-

4. Physico Chemical Properties of Steel. C. A. Edwards—Page 164.

tions two products, ferrite and cementite. It is very probable, as has been pointed out, that the carbon in austenite exists in atomic dispersion. When either Gamma or Alpha iron becomes supersaturated with carbon the excess precipitates as Fe_3C. Gamma iron is much more capable of holding carbon in solution than is Alpha iron. Line GS in Fig. 1 shows how the A3 transformation of iron is lowered with increase in carbon content. Line ES, Fig. 1

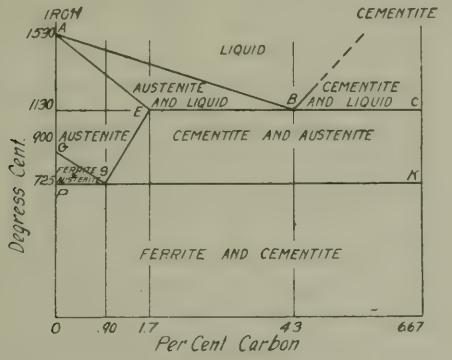


Fig. 1—Equilibrium Diagram of Iron-Cementite System.

represents the temperature solubility relations of carbon in Gamma iron. The intersection of these two lines, S, is the eutectoid point and the relation between eutectic and eutectoid is well known.

Eutectic Versus Eutectoid

Although a eutectic and eutectoid are similar in many respects, there are some important differences between the eutectic transformation and the eutectoid transformation. These differences are so far reaching in their effects as to make steel susceptible to marked improvement in hardness by heat treatment, whereas no changes of such magnitude can be brought about by treatment of eutectics. In a liquid binary alloy of eutectic composition the atoms of both constituents are present in a thoroughly dispersed state and the like atoms must get together during solidification. The molten state is one of very great freedom of movement of atoms which makes it relatively easy for the like atoms to get

together. Both constituents of a binary eutectic must crystallize from a noncrystalline liquid solution. The heat of crystallization is relatively high and solidification cannot take place without a substantial halt due to the evolved heat of crystallization. Such a halt favors the segregation of the two constituents. Furthermore, the temperature of formation of a eutectic is high, relatively, being the highest temperature or nearly so, at which the mixture is capable of existing in the solid state. These conditions favor rapid separation of the unlike atoms and the segregation of like atoms

Allotropic Change Easier Than Carbide Formation

In the iron-cementite eutectoid the ferrite is the product of transformation of atoms of iron from one crystalline form to another, a weaker change than that of liquid to crystal; the change involves less energy and is more easily retarded by rapid cooling. The eutectoid, pearlite, can even be heated somewhat above its equilibrium transformation point without changing to austenite, a thing never observed in the change from the crystalline to the liquid state. The other product of the eutectoid transformation, cementite, (Fe_3C), cannot form without diffusion of carbon through solid crystalline metal. The change of Gamma iron to Alpha iron involves only minor movements of the iron atoms. Formation of cementite from iron atoms and carbon atoms, the latter being as far apart as they can get in the Gamma iron space lattice, involves diffusion of the carbon. This requires much more time than that required for the transformation of the iron from one space-lattice to another. It is not surprising therefore, that the allotropic transformation from Gamma iron to Alpha iron can be effected without allowing any substantial amount of cementite to form. Furthermore, it is not surprising that rapid cooling of high carbon austenite suppresses the allotropc transformation to a temperature of 300 degrees Cent. (572 degrees Fahr.) or less.

Martensite

When the allotropic transformation of the iron takes place on quenching a carbon steel without the simultaneous formation of the carbide, the carbon is very likely temporarily trapped in atomic dispersion in the transformed austenite. The product of this

quenching in which the carbide formation is temporarily suppressed is the constituent of steel called *martensite*.

Martensite has a variable carbon content, being the same as that of the austenite from which it was formed at the moment of the allotropic transformation. Its properties vary with the carbon content and with physical differences such as those due to different quenching temperatures or maximum temperature of treatment before quenching. Carbon steels containing less than about 0.15 per cent carbon do not form hard martensite when quenched from above the upper critical temperature. Carbon steels containing about 0.2 per cent carbon form a medium hard, but ductile martensite when rapidly quenched from above the upper critical temperature. The hardness increases with the carbon content up to about 0.7 per cent carbon, above which there is little change in hardness up to about 1.5 per cent carbon. The lower the carbon content the more drastic must be the quench in order to produce martensite. For example, the mildest quench which will produce 100 per cent martensite in a 0.9 per cent carbon steel, will produce free ferrite, martensite and troostite (or sorbite) in a 0.2 per cent carbon steel, and martensite and troostite in a 0.5 per cent carbon steel.

Microstructure of Martensite

Martensite, under the microscope, appears to be devoid of specific structure except a tendency toward the so-called "acicular" or needle-like markings, having the same angles as the crystallographic planes of the mother austenite grains. The larger the austenite grains from which the martensite is formed, the more pronounced are these markings. The martensite of commerce is usually produced by quenching fine-grained austenite and consequently it does not possess the marked acicular structure usually considered as typical. Fig. 2 is a bearing steel containing high carbon, and some chromium and quenched from 1035 degrees Cent. (1900 degrees Fahr.) Coarse-grained austenite existed prior to quenching and the markings are typical of acicular martensite. The conditions in this case were such that some austenite was preserved by the quench.

Retention of Austenite

The retention of austenite at ordinary temperature is favored by the presence of nickel, as mentioned above, by chromium, by manganese and by high carbon. Austenite is not nearly as hard as martensite. Transformation of austenite to martensite is, therefore, accompanied by an increase in hardness. Since the

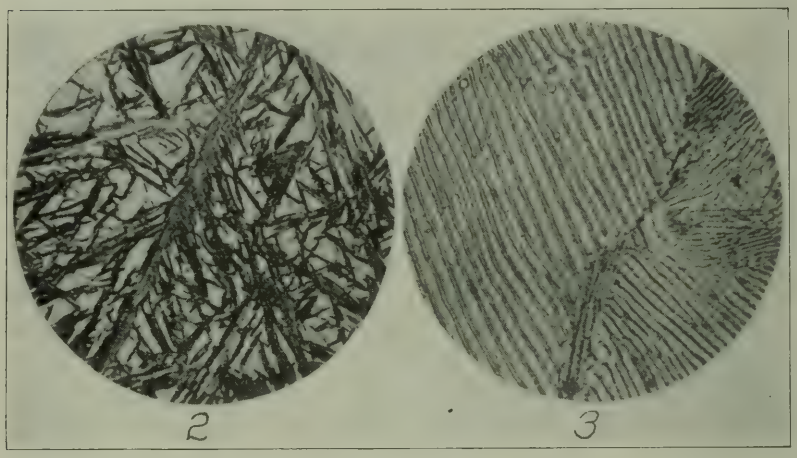


Fig. 2—Martensite and Austenite in Bearing Steel. X 100. Fig. 3—Lamellar Pearlite. X 1000 (H. O. Walp—S. K. F. Research Laboratory).

face-centered cubic crystal lattice of austenite represents closer packing of the atoms than the body-centered lattice of Alpha iron or martensite, the transformation of austenite to martensite is accompanied by an increase in volume. Those elements which when present in considerable amounts are conducive to the retention of austenite on quenching, are when present in small amounts conducive to the formation of martensite on quenching. These elements can be substituted for part of the carbon in steel but no element has been found which can entirely replace carbon in iron-base alloys. The alloy steels form martensite on quenching more readily than carbon steels. This difference is very apparent in large sections of steel which form a much thicker hard layer on on the surface with alloy steel than with carbon steel.

Pearlite, Sorbite and Troostite

The rate of cooling any steel from the critical temperature is a most important factor in determining its structure and hence its properties. Let us consider the effect of various rates of cooling a 0.9 per cent carbon steel from the austenitic state. There is only one phase, namely, Gamma iron in which 0.9 per cent carbon is dissolved (austenite). If cooled very slowly through the critical range pearlite is formed in which the cementite tends toward globular particles large enough to be seen under the microscope at say 100 to 200 magnifications. With somewhat more rapid cooling such as the air cooling of a piece of steel about 1 inch on a side, the well known lamellar pearlite, as shown in Fig. 3, is formed. The more rapid the cooling the smaller the cementite particles become until a size of particle is reached which is no longer resolvable under the highest powered microscope. In accordance with the etching characteristics of these mixtures of ferrite and fine particles of cementite, they are termed sorbite or troostite. These constituents in steel are not very well defined, as might be expected, because they do not represent phase differences, but only changes in grain size of the same constituents.

Formation of Martensite

The temperature of transformation of the austenite becomes lower the more rapid the cooling rate. As the transformation temperature becomes lower the ferrite grains become smaller and the cementite particles become smaller. The lowering of the temperature of the transformation, however, is not continuous as the rapidity of the cooling increases. When the cooling rate is proper to lower the transformation temperature to about 600 degrees Cent. (1112 degrees Fahr.) troostite, consisting of fine-grained ferrite and small particles of cementite, forms. When the cooling rate is sufficient to lower the transformation temperature substantially below 600 degrees Cent. there seems to be no change in the austenite until a temperature in the neighborhood of 300 degrees Cent. (572 degrees Fahr.) is reached. At this temperature or at some lower temperature the allotropic transformation from Gamma iron to Alpha iron takes place without the formation of cementite. The freshly formed product of such a quench is, there-

fore, different phasially from troostite, sorbite, or pearlite. There seems to be very little difference in the quenching rate required to produce martensite and troostite as evidenced by the simultaneous occurrence of these two constituents in many quenched steels. The point to be emphasized in this connection is the discontinuity in the lowering of the transformation temperature of austenite with progressively faster cooling rates. If the austenite can be cooled fast enough to reach a temperature below about 600 degrees Cent. (1112 degrees Fahr.) without transformation, there seems to be a considerable temperature range within which it is more stable than above about 600 degrees Cent. or below about 300 degrees Cent.

Formation of Cementite from Martensite

As mentioned above, no substantial diffusion of atoms is necessary in the transformation of face-centered iron to the body-centered lattice. Since carbon is very much less soluble in Alpha than in Gamma iron, there is a strong force toward precipitation of carbide as soon as the iron transformation has taken place. In order for cementite to form, however, the carbon atoms must diffuse. Carbon can diffuse slowly at room temperature in the iron lattice and does so, forming cementite. At higher temperatures the reaction takes place more rapidly. The result of the carbide precipitation under these conditions is decidedly different from that when the carbide forms at or above about 600 degrees Cent. The cementite forms from more centers at the lower temperatures, and at some stage of the precipitation the particles must be of critical size to produce maximum hardness.

Freshly formed martensite, therefore, is composed chiefly of Alpha iron holding carbon atoms in atomic dispersion. Martensite which has stood at room temperature for a considerable time, or which has been subjected to elevated temperatures below those at which the martensite may be regarded as having transformed into troostite, consists of ferrite and innumerable small particles of cementite. The ferrite may or may not contain more than the equilibrium quantity of carbon in atomic dispersion, or true solution.

Grain Size of Martensite

Because of the low temperature at which it is formed and the obstructing effect of the carbon in solution, the grain size of the Alpha iron of which martensite is composed is very small.

Causes of Hardness of Martensite

After considering all of the evidence the authors have concluded that the hardness of martensite is due chiefly to the fineness of the ferrite grains. The presence of carbon atomically dispersed in this ferrite to form a forced solid solution also contributes to the hardness of the product but is a small factor as compared with the grain size. Crystalline cementite is very hard and strong and meets all of the requirements of a good "key" material. The formation of particles of cementite in martensite is, therefore, an additional source of hardness. At some stage in the formation and growth of the cementite particles their size is such as to produce maximum hardening effect. It is not probable that all of the cementite particles reach critical size at the same time.

Growth of Cementite Particles

After the cementite formation has progressed nearly to completion, the larger particles grow by absorbing carbon in solution in the ferrite. The ferrite is supersaturated in carbon with respect to the larger particles and saturated with respect to smaller particles of cementite. The precipitation of the carbide on the larger particles produces a condition of undersaturation with respect to smaller particles which then are dissolved. The carbon atoms diffuse toward regions of low concentration which is toward the larger particles. Growth of cementite particles during tempering is thus favored by a long time and high temperature. The successive stages of troostite, sorbite and granular pearlite represent in part progressive increase in size and decrease in number of the cementite particles.

Ferrite Grain Growth

As these changes in the carbide are progressing there must be some changes in the ferrite. In the case of a steel containing 1 per cent carbon, the formation of cementite requires about 15 per cent of the iron. This iron must be supplied from the ferrite or

from any amorphous iron which may be present. Such a change is toward a more perfect equilibrium in the ferrite which tends toward softening. It seems certain that the growth of the ferrite into larger particles at temperatures from 350 to 550 degrees Cent. (662 to 1022 degrees Fahr.) is an important factor in the decrease of hardness. The effect of changes in the ferrite caused by low tempering (below 300 degrees Cent.) is small, but even this becomes appreciable in the harder martensites.

Opposing Nature of Ferrite Grain Growth and Cementite Precipitation

The first stages of tempering martensite, therefore, involve two opposing factors; the changes in the ferrite tend to produce softening, while the first precipitation of the cementite tends to harden. We might expect an increase or decrease in hardness according to the rapidity and extent of these opposing changes. It does not appear that a hard steel will ever soften at ordinary temperature. This indicates that there is no considerable growth of ferrite at room temperature even after many years, and the cementite particles do not reach a supercritical size. Long exposure at about 100 degrees Cent. seems to produce slight softening in very hard martensite.

Summary

The essential points in connection with the hardening and hardness of steel are as follows:

1. Steel owes its hardness fundamentally to the absolute cohesion of the iron atoms.

2. Pure iron and soft steels are relatively soft and weak, because of the presence of crystallographic planes of weakness or potential slip planes in the iron or ferrite grains.

3. The increased hardness and strength of pearlite as compared to pure iron are due largely to the increased resistance to slip in the ferrite grains offered by the hard intermetallic compound, cementite.

4. The increased hardness of sorbite and troostite as compared to pearlite is due to the refinement of the ferrite grains and the greater dispersion of the cementite particles.

5. The increased hardness of martensite, as compared to troostite and sorbite is due to a still greater refinement of the ferrite grains and in cases of maximum hardness to the critical dispersion of the cementite particles. Carbon in solution or in atomic dispersion in the ferrite makes the ferrite of martensite somewhat harder than the ferrite of pure iron.

6. The more rapid the cooling of austenite the lower will be the temperature of its transformation into ferrite and cementite. When the transformation takes place at or above a temperature of about 600 degrees Cent. (1112 degrees Fahr.) both ferrite and cementite form, yielding pearlite, sorbite or troostite. If the austenite is preserved at a temperature less than about 600 degrees Cent. it seems to be relatively stable until a temperature of about 300 degrees Cent. is reached on cooling.

7. When the austenite transformation is suppressed to about 300 degrees Cent. or lower, the allotropic transformation of the iron takes place independently of the carbide formation. Freshly formed martensite, therefore, consists essentially of Alpha iron in which the carbon is substantially atomically dispersed. Freshly formed martensite is apparently not quite as hard as martensite which has stood at room temperature for several days or has been given a mild tempering treatment.

8. Carbon is very much less soluble in Alpha iron than in Gamma iron. The Alpha iron of freshly formed martensite contains the carbon atoms in atomic dispersion. The Alpha iron of freshly formed martensite is, therefore, supersaturated with respect to carbon. Equilibrium is brought about only by the precipitation of the carbon in the form of cementite.

9. Carbon diffuses slowly in Alpha iron at room temperature and diffuses more rapidly as the temperature is increased. The carbide, therefore, precipitates slowly at room temperature and more rapidly with rising temperature.

10. It is postulated that freshly formed martensite is hard chiefly because of the fineness of the ferrite grains but partially because the ferrite containing carbon is harder than pure ferrite.

11. It is postulated that the increase in hardness of freshly quenched martensite on standing at room temperature or after mild tempering is due to the precipitation of cementite, the hard cementite particles "keying" the slip planes of ferrite grains.

12. Heating tends to soften the martensite because it tends to produce growth of the ferrite grains.

13. Heating produces changes in the carbide which tend to harden the steel until critical dispersion of the carbide particles obtains, and further heating tends to soften.

14. Growth of the carbide particles is considered to take place as the result of a slight solubility of carbon in Alpha iron, which is greater the smaller the size of the cementite particles with which the solution is in contact. There is a tendency for the carbon concentration in the ferrite to be equalized by diffusion. With equal carbon concentration in the ferrite, carbon will precipitate on the large particles causing a flow of carbon atoms toward the large particles, thus making the Alpha iron undersaturated with respect to small particles of carbide. The small particles are then dissolved with the result that the change is toward fewer and larger particles of carbide.

15. The mechanism of particle growth is such that the matrix, Alpha iron, should approximately reach its equilibrium content of carbon before the laws of particle growth would begin to apply. This suggests the nearly complete precipitation of the carbide at an early stage of tempering

16. Sometimes the composition of the steel is such that rapid quenching preserves austenite at room temperature, whereas moderate rates of cooling do not preserve austenite. The transformation of such austenite to martensite or to another product of transformation on ageing or tempering results in an increase in hardness. An increase in the hardness of a steel due to this cause is accompanied by an increase in volume.

The conception of the hardening of steel presented above will be more fully discussed in the following, and further evidence will be given supporting certain of the conclusions reached.

High Absolute Cohesion of Iron Atoms

That there is high cohesion between iron atoms is apparent from the hardness and strength of cold-worked iron, and from the energy required to separate iron atoms from one another by

evaporation. Iron cannot, however, by cold working be made to develop the maximum hardness or strength which it inherently possesses. The extreme condition of cold working occurs in fine wire drawing. Iron drawn to the finest sizes shows a strength of about four times that of annealed iron. The fracture always shows marked reduction of area. This indicates movements of considerable extent on slip planes during fracture, and when such slip occurs the absolute cohesion of the atoms is not developed.

In carbon steels heat treatment is more effective than cold work in developing slip interference. A steel containing some what over 0.4 per cent carbon can be hardened and strengthened to a marked degree by quenching. Such a steel has one carbon atom to 50 iron atoms. All of the structural evidence indicates that in such a quenched steel the iron atoms are continuous and the carbon atoms are discontinuous. If the iron atoms are continuous, as seems practically certain, then short paths of rupture are numerous in all directions, which would involve only the separation of iron atoms. If, therefore, the absolute cohesion of the iron were not high it would not be possible to make steel so hard and strong. Alloying and heat treatment combine to make steel hard chiefly by making more effective the cohesion bonds between the iron atoms. Pure iron is soft because of the ease of slip on slip planes, and the hardening is due to interference with slip. We have now to consider the specific ways in which slip is interfered with.

Hardness of Granular Pearlite, Sorbite, and Troostite

These constituents represent different degrees of refinement of the ferrite grains and cementite particles, which are coarsest in pearlite and finest in troostite. Pearlite may be more than twice as hard as pure iron and troostite may be three times as hard as pearlite. The slip interference in these constituents is due mostly to the keying action of the cementite and to the refinement of the ferrite grains.

There is good agreement as to the nature of pearlite, sorbite and troostite.

The Nature of Martensite

Although definite ideas have been given regarding the nature of martensite, there has been much contention for 35 years on this point. It is considered desirable, therefore, to carefully review the evidence for the views given earlier in this paper.

The reasons for believing that the carbon atoms are in atomic dispersion in austenite have been given. According to this view the only existence of the compound cementite is as a crystalline substance. Crystalline Fe_3C is formed directly from iron and carbon atoms and not from molecules of Fe_3C. It is considered by the authors that there is no molecule containing only three atoms of iron and one of carbon. If the carbon is in atomic dispersion in austenite, then it will remain in atomic dispersion in transformed austenite (martensite) until cementite forms.

There is considerable evidence that in the transformation of austenite into martensite the allotropic transformation of the iron takes place and that it takes place before and independently of the cementite formation. This evidence is of a varied nature involving volume changes, changes in magnetic properties, thermal changes, etching characteristics, and X-ray crystal analysis.

Volume Changes

It is well known that the transformation of Gamma to Alpha iron takes place with increase in volume. Andrew, Rippon, Miller and Wragg[5] have shown that the formation of cementite from austenite causes a contraction. When the steel contains about 1.0 per cent carbon this contraction is sufficient to counteract the expansion due to the allotropic transformation of the iron; a 1.0 per cent carbon steel slowly cooled from the austenitic condition will, therefore, undergo no appreciable volume change other than that due to its normal temperature coefficient. When such a steel is quenched so as to form martensite, however, there is an increase in volume comparable to that accompanying the allotropic change. The expansion has been shown by Chapin[6] to take place at a low temperature, below 300 degrees Cent. and to occur simultaneously with the

5. The Effect of Initial Temperature upon the Physical Properties of Steel, *Journal*, Iron and Steel Institute, 1920, No. 1, p. 527.

6. *Transactions* of American Society for Steel Treating, March, 1922, pp. 507-14.

reappearance of magnetism and the development of marked hardness.

Brush[7] found that freshly quenched steel contracts in volume slowly at ordinary temperatures. It is well known that tempering causes a decrease in volume. Standing at room temperature seems, therefore, to produce changes corresponding to mild tempering.

When austenite is preserved at ordinary temperatures and is caused to change to martensite, there is a volume increase comparable to that due to the allotropic change.

Magnetic Properties

It is well known that austenite is nonmagnetic unless the proportion of nickel or colbalt is substantial. These elements are magnetic when crystallized with face-centered cubic lattices, and can hold considerable iron without losing their magnetic properties The transformation of nonmagnetic austenite into martensite is accompanied by a sharp increase in magnetic susceptibility. Martensite is always quite magnetic, its susceptibility approaching that of Alpha iron.

Honda[8] has observed a magnetic transformation point in cementite at about 215 degrees Cent. (420 degrees Fahr.) which he called Ao. Magnetic analysis is capable of detecting cementite in steel containing as little as 0.1 per cent carbon. Freshly quenched eutectoid martensite shows only a suggestion of the Ao point on heating, but once the steel has been heated to 300 degrees Cent. or above for a short time, the point is pronounced, indicating the presence of crystalline cementite. The effect of particle size on the magnetic properties of cementite is not known, so from the magnetic evidence alone it is not safe to draw definite conclusions as to its absence.

Thermal Changes

Portevin and Garvin[9] have studied the quenching of steel by means of cooling curves. They report that martensite forms at or below about 300 degrees Cent. on quenching. When the trans-

7. Thermal Relations in the Treatment of Steel. *Transactions* A. I. M. E. Pyrometry Volume 1920, p. 590.

8. On Magnetic Analysis as a Means of Studying the Structure of Steel. *Journal* of Iron and Steel Institute, Vol. 98, No. 2, 1918, p. 375.

9. *Journal* of Iron and Steel Institute, No. 1, 1919, p. 469

formation takes place at these low temperatures not all of the heat of the A3-2-1 transformation is evolved. This point has been studied quantitatively by Honda[10] and Yamada[11] who find that a considerable portion of the heat is quickly evolved on reheating the quenched steel to a temperature slightly below 400 degrees Cent. (752 degrees Fahr.) The amount of heat evolved on reheating was found to be proportional to the carbon content of the steel. In certain steels it was equivalent to about one-third of the heat evolved at A3-2-1 on slow cooling.

It has long been known that heat was evolved on tempering martensite. C. F. Brush, however, observed the same phenomenon

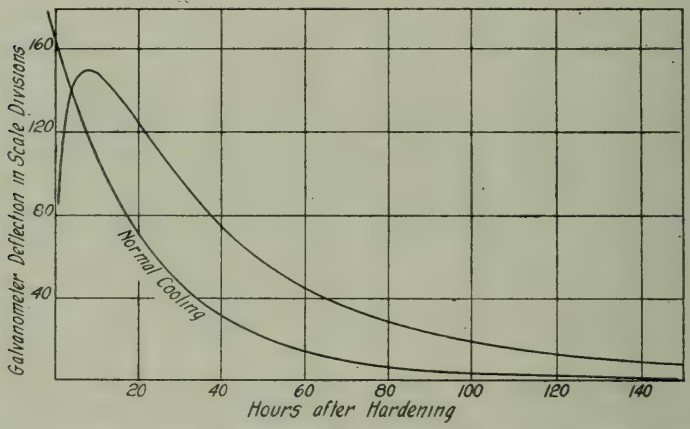


Fig. 4a—Curve Showing Spontaneous Generation of Heat in Recently Hardened Steel (Brush).

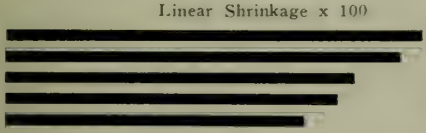
at ordinary temperature. He constructed a very sensitive calorimeter into which he put quenched steel within an hour after quenching. The evolution of heat from the steel was sufficient to increase its temperature more than 2 degrees Cent. The heat evolution seemed to be most rapid at first and to gradually lessen. The evolution of heat was sufficient to be detected, however, after 35 days. Brush's graphs showing the spontaneous generation of heat and spontaneous contraction of recently hardened steel are shown in Fig. 4a and 4b. The contraction and the heat evolution, at room temperature and on tempering, are attributed by the present authors to the formation of cementite.

10. *Chemical and Metallurgical Engineering*, Nov. 30, 1921, pp. 1001-3.
11. *Science Reports* of the Tohoku Imperial University, Vol. 10, p. 453.

Etching Characteristics

There is a marked difference between the etching characteristics of martensite and troostite and between martensite and austenite. Martensite is more resistant to acid attack than troostite but less resistant than austenite. From experience with various alloys it seems that the following generality can be made. When a second phase crystallizes from a solid solution the corrosive attack becomes only slightly more pronounced if the particle size of the new phase is very small, say smaller than critical size for maximum hardness. When the particle size becomes supercritical the corrosive attack becomes more rapid.

The behavior of martensite is in keeping with these views. The cementite in untempered or mildly tempered martensite is


Linear Shrinkage x 100
Length of Rod After Hardening
After Spontaneous Shrinking
After Tempering to Light Straw
After Tempering to Light Blue
After Annealing

	Per Cent
Length of rod after hardening	100.383
After spontaneous shrinking	100.332
After tempering to light straw	100.182
After tempering to light blue	100.131
After annealing	100.000

Fig. 4b—Shrinkage of Steel Bar Due to Heat Treatment (Brush)

present as very small particles. In troostite the cementite particles are supercritical in size and the etching or corrosive attack is more pronounced.

X-ray Crystal Analysis

The X-ray gives a positive answer on the matter of allotropic changes on quenching. When austenite is preserved at ordinary temperatures the X-ray shows that the crystal lattice is face-centered cubic or that of Gamma iron. When martensite is formed the crystal lattice is body-centered cubic or that of Alpha iron.[12] Beta iron has the same crystal lattice as Alpha iron. Since we regard a change in crystalline structure as essential in a true allotropic change we shall treat the so-called Beta iron as Alpha. There is certainly no justification for assuming a Beta iron of such hard-

12. Westgren—Roentgen Spectrographic Investigations of Iron and Steel. *Journal* of Iron and Steel Institute, 1921, Vol. 103, p. 303.
Bain—Studies of Crystal Structure with X-Rays. *Chemical and Metallurgical Engineering*, Oct. 5, 1921, p. 663.
Jeffries & Archer—Crystalline Structure of Metals. *Chemical and Metallurgical Engineering*, May 4, 1921, p. 771.

ness that its supposed retention by quenching accounts for the hardness of martensite.

When austenite is preserved at ordinary temperatures and is later transformed into martensite, the change in crystal lattice occurs simultaneously with increase in hardness, volume, and magnetic susceptibility. The X-ray thus has given a definite and final answer as to the nature of the iron in martensite. It is the ordinary Alpha iron, usually regarded as soft and weak.

The X-ray so far has not given any evidence as to the existence or nonexistence of cementite in freshly formed martensite. The authors believe, however, that the evidence given above is quite conclusive on this point.

It should be mentioned that martensite can be formed by rapidly cooling a steel from above the critical temperature to about 200 degrees Cent. Chapin formed martensite in this manner. Obviously cementite will form more rapidly at 200 degrees Cent. than at room temperature. Within a few minutes after the martensite is formed there should be as much cementite formed as after several weeks at room temperature. That this is the case is indicated by the fact that the volume increase is slightly smaller when martensite is formed at 200 degrees Cent. than when the steel is cooled quickly to room temperature.

Hardness Changes on Tempering

Too little is known regarding the exact sequence of hardness changes on tempering quenched carbon steels. The most marked effect is one of softening, and the opinion is fairly general that softening is progressive throughout the whole range of tempering temperatures. It is certain that the tempering of hardened tool steel at temperatures above 200 degrees Cent. reduces its cutting hardness and probably also its Brinell hardness. The Shore scleroscope hardness of tool steel seems to be less affected by tempering at low temperatures. It is likewise quite certain that steels of medium carbon content which have been hardened are softened by tempering at temperatures above 350 degrees Cent., as proved by thousands of tests on hardness and tensile strength. The hardness of low-carbon steels is known to be not greatly changed by tempering, and the changes brought about by tempering above 500 degrees Cent. are certainly in the direction of soften-

ing. Steels of the various carbon contents are seldom tempered commercially at temperatures below those which produce easily measurable softening. There is, therefore, a lack of results of commercial practice in the tempering of hardened steels at very low temperatures.

It is stated by Heyn and again by Boynton that tempering, even in its early stages, gradually reduces the hardness of mar-

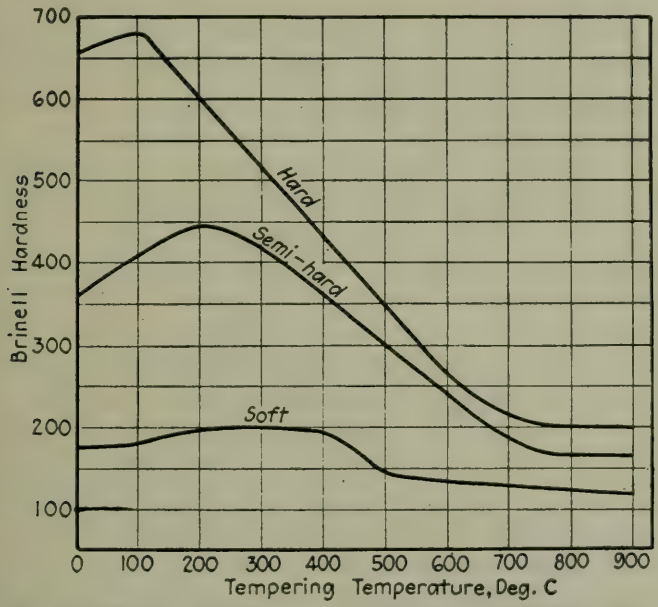


Fig. 5—Effect of Tempering on the Hardness of Hardened Steel (Grard)

tensite. Heyn's conclusions are drawn from scratch hardness tests on high-carbon steel.

Among the few published contributions on this subject is a paper by C. Grard in which it is reported that the first effect of tempering is to increase the hardness. His results are plotted in Fig. 5. They are described as typical of the steels of the classes named. No analyses are given.

While Grard's curves are opposed to general opinion, it is believed that they merit serious consideration as representing perhaps an overlooked phenomenon in the tempering of steel. He appears to have made a particular point of the accuracy of his

hardness determinations. These were also confirmed, in the case of the soft and semihard steels, by tensile strength results which parallel the hardness results closely; hard steels were too brittle for satisfactory tensile tests after low tempering temperatures. It is to be noted that the maximum hardness attained on tempering occurs at a lower temperature the higher the initial hardness. Marked softening also begins at lower temperatures the higher the initial hardness.

Honda and Idei[13] have made extensive studies of the hardness of recently quenched carbon steels. Their general conclusions with reference to the distribution of hardness with various rates of cooling are given in their own words as follows:

"In small pieces of steel, such as a square or a short cylinder, the periphery is harder than the central portion only when the quenching is very soft. In a moderate quenching the hardness is everywhere nearly equal; but in a hard (drastic) quenching the periphery is always softer than the interior. This anomalous phenomenon is explained by the presence of the arrested austenite."

These authors give as the chief evidence of the retention of austenite in the hard quenchings, the increase in hardness of hard quenched steels with considerable lapse of time at ordinary temperatures and more quickly at 100 degrees Cent. They state: "According to the above view, in a hard quenched steel, some austenite remains untransformed at room temperature, at which this austenite will slowly transform into martensite. On the other hand, at room temperature, martensite has a tendency further to be transformed into troostite, but the velocity of this change is much smaller than that of the austenite→martensite change just referred to. The consequence is that at room temperature a hard quenched specimen will slowly increase in hardness with lapse of time. To test this inference, the hardness of a quenched specimen was measured from time to time, as in the usual way and its mean value plotted against the time passed after the quenching. Fig. 6 is a graphical representation of the result of our experiments, which agree completely with our expectation. The hardness increases at first rapidly and then slowly, tending to an asymptotic value as the time elapses.

13. On the Distribution of Hardness in Quenched Carbon Steels and Quenching Cracks, *Science Reports* of the Tohoku Imperial University, Vol. 9, No. 6, 1920.

"If the quenched specimen is constantly heated at 100 degrees Cent. instead of letting it remain at room temperature, the above change from austenite will be much accelerated; at the same time the change from martensite to troostite will also be accelerated. Hence the hardness must at first increase, reach a maximum and then slowly decrease. As shown in Fig. 7, this conclusion is actually brought out by experiments."

Although austenite is retained at ordinary temperature on

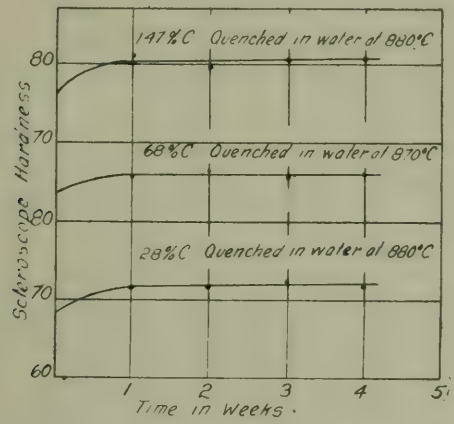


Fig. 6—Effect of Room Temperature Aging on the Hardness of Quenched Steel (Honda and Idei)

quenching certain steels and causes an increase in hardness when and if it transforms to martensite, its retention in ordinary carbon steels as postulated by Honda and Idei seems highly improbable. When austenite is retained in any substantial amount its presence can be detected by X-ray analysis. The X-ray gives no indication of the retention of austenite in steels similar to those used by Honda and Idei. When austenite transforms into martensite it does so with increase in hardness and volume and with evolution of heat. Brush found that recently quenched carbon steel evolves heat spontaneously but the heat evolution is accompanied by a *decrease* in volume. Unless Honda and Idei can show an increase in volume accompanying the increase in hardness, it is almost certain that the hardness increase is due to some change other than the transformation of austenite to martensite.

The explanation put forward in the earlier part of this paper conforms to all of the observed facts. The spontaneous hardening, evolution of heat and contraction are due to the precipitation of cementite. In a hard quenching the outside layers of the steel cool to ordinary temperature so rapidly that practically no cementite

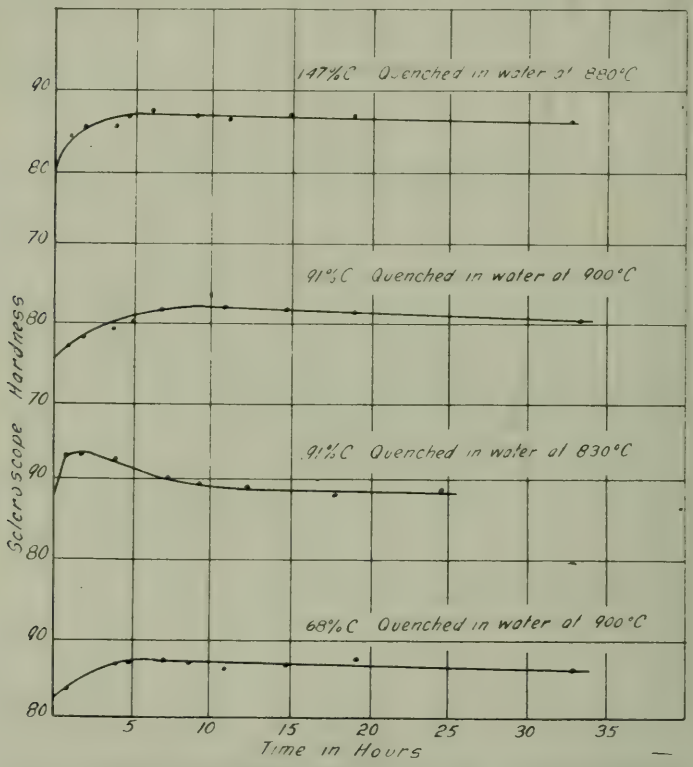


Fig. 7—Effect of Tempering at 100 Degrees Cent. on the Hardness of Quenched Steel (Honda and Idei)

has formed. Maximum hardness does not obtain until cementite particles form. The formation of cementite takes place slowly at room temperature and more rapidly as the temperature is increased. The rate of cementite formation is governed largely by the rate of diffusion of carbon in the Alpha iron lattice. There is no indication that the transformation of austenite to martensite takes place so gradually. This transformation is usually quite sudden when conditions are proper. This accords nicely with the curves in Figs. 6 and 7.

With a medium quench the steel remains a sufficient time below about 300 degrees Cent. and above room temperature to cause precipitation of considerable cementite. If the quench is too soft, troostite may form or cementite particles of supercritical size may form from the martensite.

Frequently large pieces of quenched steel will not be cracked immediately after quenching but will crack within a few minutes, hours or days. Such cracking would not be expected to take place if the views of Honda and Idei are correct. They would postulate the existence of martensite and troostite in the interior and martensite containing some untransformed austenite in the outer layers. The slow transformation of the austenite should produce an increase in volume in the outer layers and hence reduce the tensile stresses. This should prevent cracking. On the other hand if cementite precipitation occurs in the outer layer, contraction would take place with increase in the tensile stresses. This would promote cracking. It is thus evident that the results of Honda and Idei can be more satisfactorily explained by the spontaneous precipitation of cementite from recently formed martensite than by the transformation of austenite to martensite.

Evidence That Martensite Is Fine Grained

It was postulated that the ferrite of martensite is fine grained and that the hardness of martensite is due, in large measure, to the fine-grained structure. To account for the great hardness of martensite on this basis, it must be considered that the grain size in martensite is very minute, in fact submicroscopic. There is no direct quantitative method of measuring the grain size in martensite, but there is indirect evidence which shows that it is very small.

It should perhaps be explained what is meant by the grain size of martensite. Martensite is a decomposition product of austenite. The martensitic structure formed by quenching austenite shows many traces of the original austenite grain size. Fracture commonly follows the grain boundaries of the parent austenite. Certain methods of etching frequently reveal these pseudo grain boundaries at the same time failing to reveal any clear structure within them. It may, therefore, appear that these are the true grain boundaries in the martensitic structures.

These pseudo grains are in reality made up of a large number of differently oriented grains of Alpha iron. It is these grains whose small size is held to be responsible for the hardness of martensite and it is this grain size to which the following discussion refers.

The conditions governing grain growth in metals under various circumstances have been worked out and it can be said with considerable assurance of certainty that the conditions obtaining during the formation of martensite are such that the grain size of the Alpha iron in martensite must be very small.

While it is impossible to observe the grains in martensite directly with the miscroscope, it can be inferred from microscopic examination of other structures that the grains in martensite are too small to be seen.

The X-ray spectrometer gives evidence of a direct but qualitative nature that the grain size in martensite is very small.

Nuclei Formation in Martensite

The temperature at which martensite is formed in carbon steel is about 300 degrees Cent. or lower. This is at least 400 degrees Cent. lower than the temperature at which Alpha iron forms from austenite under equilibrium conditions. Such undercooling is known in many instances to cause the formation of a very large number of nuclei of the new phase. For example, if water slightly undercooled below the normal freezing point is agitated, there immediately forms a slush much resembling a mixture of fine snow and water. If such a slush is frozen it is found to be fine grained as compared to ice formed by normal freezing. Similarly if ordinary glass which is amorphous is heated so as to cause devitrification the crystals formed are smaller and more numerous the lower the temperature. The number of Alpha iron nuclei which form in austenite must be greater as the amount of undercooling increases.

Grain Growth

It is well known that the rate of grain growth in metals increases with temperature and that normally the extent to which grain growth proceeds also increases with temperature. In many

metals it seems that there is a fairly definite equilibrium grain size which is more or less stable at each temperature of annealing. Severely cold-worked iron shows visible recrystallization on heating to about 450 degrees Cent. There seems to be some submicroscopic grain growth at temperatures below 300 degrees Cent., but it takes place slowly and is very limited in extent. Martensite is formed at a temperature of 300 degrees Cent. or lower where any grain growth occurring in Alpha iron must be very small, and must require considerable time.

Obstructing Effect of Carbon

Grain growth in metals is hindered and sometimes entirely prevented mechanically by the presence of obstructing material. A case which has been completely worked out and reported is that of thoria in tungsten. The presence of carbon in austenite at the time of its transformation must oppose the growth of the ferrite grains which form. Its presence would impede grain growth both during and after the transformation.

It may be considered that the presence in austenite of carbon atoms in substantially uniform distribution divides the iron atoms into groups. The smaller these groups, that is, the greater the carbon content, the more stable is the Gamma iron lattice as shown by the lower equilibrium temperature of the transformation. When the carbon content exceeds about 1.5 per cent, the stability of the structure is so great that some austenite may be preserved at room temperature by rapid quenching from above the upper critical temperature. It would seem that the existence of these repeating groups of iron atoms would be conducive to the formation of many Alpha iron nuclei.

Evidence of the Microscope

Microscopic examination of martensite reveals no Alpha iron unit that could be classed as a grain, yet the X-ray spectrometer shows beyond a doubt that martensite is chiefly crystalline Alpha iron. This suggests that the crystalline units are submicroscopic, that is, less than about one one-hundred-thousandth of an inch in diameter.

When pure Gamma iron is quenched the Alpha iron grains are smaller than are produced by slow cooling. As carbon is added to the Gamma iron the Alpha iron grains not only become smaller on slow cooling, but the effect of cooling rate on the grain size becomes much more marked than with pure Gamma iron. In a hard quenched 0.2 per cent carbon steel, the ferrite may be so fine that it is not discernible as individual grains, under the microscope. The inference is that a greater carbon content would cause the formation of still smaller ferrite particles with hard quenching.

We should expect all of the refinement of grain at the time of the transformation of Gamma to Alpha iron. After the Alpha iron has been formed, any change in its structure should be toward greater stability, which is toward larger grains. Tempering martensite at 400 degrees Cent. to form troostite could not, therefore, represent a change toward greater refinement of grain than existed in the martensite; the change must be in the other direction. Yet in troostite so formed there is no indication of the presence of grains of ferrite large enough to be seen with the highest powered microscope. Again the inference is irresistible that the grains of Alpha iron in martensite are submicroscopic.

Evidence of the X-ray Spectrometer

In order to obtain a good Hull pattern with the X-ray spectrometer, it is necessary that the specimen be fine grained. In a 0.35 per cent carbon martensite, formed by quenching from 1300 degrees Cent. (2372 degrees Fahr.) the Alpha iron pattern was typical of that obtained from fine grained metals, even though the austenite grains from which the martensite was formed were large enough to be seen with the unaided eye. Not only were all of the diffraction lines of Alpha iron present on the film but these lines were wider than are obtained with ordinary grain size. The width of the lines was comparable to that obtained in X-ray crystallograms of such fine particles as collodial gold. The X-ray affords a method of measuring grain size, in a qualitative way, and gives positive proof that the grains of the Alpha iron of martensite are very small. Bain estimates that the average diameter of the grains in martensite is about 100 to 200 atom diameters (ap-

proximately .000001—.000002 inch). This figure is, of course, only an estimate, but it should be of the right order of magnitude.

Shape of Grains in Martensite

It is not to be understood that the ferrite grains in martensite are necessarily equiaxed. The conditions obtaining during their formation are conducive to the formation of very small plates of ferrite running parallel to the cleavage planes of the austenite. Whether the grains are substantially equiaxed or in plates, their formation along the austenite cleavage planes gives rise to the acicular structure of martensite. The tendency for this cleavage precipitation is so marked that martensite formed by quenching large grains of austenite appears under low magnification to have a grain structure similar to that of the austenite. Detailed examination, however, reveals the fact that the austenite grain structure is entirely replaced by a structure so fine that it is often impossible to find a single crystalline particle large enough to be seen with a high-powered microscope. The apparent crystalline masses observed after light etching are seen to be, after deep etching, complexes of very fine structure.

Hardening Effect of Grain Refinement

The hardening effect of grain refinement is shown in many metals and alloys and is well known. The most complete correlation of grain size and hardness is perhaps the work of Bassett and Davis[14] on Alpha brass. This alloy consists structurally of a single homogenous solid solution, and is, therefore, comparable to a pure metal. Some typical values obtained in one series were:

Average Grain Diameter in Inches	Brinell Hardness
0.014	41.7
0.0046	49.2
0.0030	52.4
0.0014	62.4
0.00093	77.4

The effect of moderate changes in grain size on hardness is relatively slight and it may therefore seem somewhat strange

14. "A Comparison of Grain Size Measurements and Brinell Hardness of Cartridge Brass." W. H. Bassett and C. H. Davis, *Transactions* A. I. M. E., Vol. 60, p. 428.

to ascribe the great hardening effect in steel to grain refinement. It will be noted from the above table that the grain diameter of the second specimen is more than 50 per cent greater than the grain diameter of the third, whereas the hardness has only decreased about 6 per cent. The difference in grain size would be quite apparent under the microscope while the difference in hardness is not very marked. Nevertheless the total variation in hardness brought about by changes in grain size is quite considerable. The smallest grain size observed in brass by Bassett and Davis is large compared to the grain size which the authors believe to exist in martensite.

Role of Amorphous Iron

Martensite is essentially crystalline. This is evident from X-ray and other information. Any amorphous iron present would be either at grain boundaries or at slip planes. The amount at slip planes would be slight because the volume change when martensite forms is only 1.5 per cent. If amorphous iron is any considerable factor in the hardness of martensite, it must be the grain boundary amorphous iron. If the grain boundary amorphous iron is much of a factor, the grains must be very small so that the grain boundary surface will be large.

Dissolved Carbon as a Cause of Hardening

It has been stated by Le Chatelier and the opinion is held by others, that martensite owes its hardness to carbon in solid solution in Alpha iron. The evidence given above is quite conclusive on the point that mildly tempered martensite contains very little carbon in solid solution, the bulk of it being precipitated as cementite. Such martensite is hard and the hardness cannot be due to carbon in solid solution. Great hardening can be produced in a steel containing two atoms per cent of carbon. No case is known where two atoms per cent of one element dissolved in a large grained metal produces hardening at all comparable to that in the case of martensite containing two atoms per cent of carbon. In austenitic manganese steel there may be as much as seven atoms per cent carbon and twelve atoms per cent manganese dissolved in Gamma iron without producing any such marked hardening. The structure in this case is coarse grained. It may be argued that

two atoms per cent of carbon produce over six per cent of cementite and that it is this compound which is in solid solution in the ferrite. The same argument (though previously shown to be highly improbable) applies to manganese steel which would have more than twenty per cent cementite in solid solution.

It is probable that a given amount of carbon in atomic dispersion in Alpha iron would produce a greater hardening effect than in Gamma iron.[15] In order to completely account for the hardness of martensite in this manner, however, the hardening effect of carbon would have to be about fifteen times as great in Alpha as its maximum possible effect in Gamma iron as shown for example in austenitic manganese steel. According to this view, the addition of minute quantities of carbon (less than is soluble in Alpha iron at room temperature) to pure iron should produce a marked increase in hardness, which is not in accord with the facts.

Although some of the hardness of freshly formed martensite can be attributed to the atomic dispersion of carbon in Alpha iron, it seems to the authors that this is of secondary importance. In other words, if the Alpha iron containing the atomically dispersed carbon were coarse grained, it is the authors' belief that it would be relatively soft. On the other hand, if the grains of pure Alpha iron could be made as small as the Alpha iron grains of high carbon martensite, it is the opinion of the authors that relatively great hardness would result. Grain refinement is thus given as the most important cause of the hardness of freshly formed martensite, and the presence of carbon as a secondary cause.

Some Characteristics of Austenite

A general effect of alloying elements such as nickel, chromium and manganese, is to facilitate the formation of martensite on quenching. That is, the cooling velocity required for the formation of martensite is less when these elements are present. Whereas a piece of carbon steel one inch in diameter will, when quenched in water, form an outer layer of martensite about 1/8-inch thick and a martensite-troostite interior, a piece of alloy steel the same size will form martensite throughout under the same conditions.

15. Rosenhain, Solid Solutions. Lecture February meeting of A. I. M. E., 1923.

The addition of these alloying elements also makes it easier to retain austenite at ordinary temperatures on quenching. The various kinds of austenite have different characteristics. The high carbon (1.8) low manganese (1.5) austenite can be transformed into martensite either by cooling in liquid air or by mild heating. Most of the varieties of room temperature austenite containing high carbon and a relatively small amount of other alloying element can be transformed to martensite by either cooling in liquid air or mild heating.

Hadfield's manganese steel (manganese about 12 per cent) when in the austenitic state is, however, very reluctant to transform to Alpha iron. The austenite is so stable that no ordinary heat treatment will cause its transformation. Mechanical work causes a partial transformation to martensite with consequent increase in hardness. The transformation from Gamma to Alpha iron proceeds slowly at a temperature of 500 to 700 degrees Cent. (932-1292 degrees Fahr.) The austenite of manganese steel is greatly supersaturated with carbon at room temperature or at any temperature below 700 degrees Cent. It appears that much carbide precipitation in this case precedes the Gamma to Alpha transformation. The precipitation of carbide is apparently required to make the austenite less stable.

The precipitation of carbide from the austenitic manganese steel, without a simultaneous transformation of Gamma to Alpha iron, is quite analogous to the precipitation of the hard intermetallic compounds in duralumin. It has been stated that austenitic manganese steel heated to 500 degrees Cent. (932 degrees Fahr.) hardens much more rapidly than it increases in magnetism. Most of the hardness increase occurs before the specific magnetism has reached two per cent (Pure iron equals 100 per cent) and before there is any marked change in the visible structure.[16]

But manganese steel cannot be made very hard. The temperature at which the austenite transforms to martensite is such that grain growth of the ferrite can take place and the carbide particles will grow beyond the size for maximum hardness.

Structural Constituents in Steel

It may be of interest to summarize the views given above

16. Metals and the Common Alloys. S. L. Hoyt, pp. 347-9.

regarding the nature of the various constituents occuring in steel.

Austenite

A solid solution of carbon in Gamma iron. The iron atoms have the face-centered cubic arrangement. The carbon is atomically dispersed. The carbon atoms may be substituted for some of the iron atoms in the face-centered cubic lattice, or may occupy positions between the iron atoms. Austenite is relatively soft and ductile.

Martensite

Very fine grained Alpha iron containing carbon which, immediately after the formation of martensite, is atomically dispersed but not in true or stable solid solution. The iron atoms have the body-centered cubic arrangement. On aging at room temperature or more quickly on mild tempering, small particles of crystalline cementite form by the gradual diffusion of the carbon atoms and their association with iron atoms. The hardness of martensite increases with its carbon content and becomes very great at 0.70 per cent or more of carbon. At the same time ductility practically disappears. Martensite is formed from austenite on cooling at about 300 degrees Cent. It is not a stable phase at any temperature.

Troostite

An emulsion of very small cementite particles in fine-grained Alpha iron. Differs from martensite which has been aged or slightly tempered only in the larger size of the cementite particles and Alpha iron or ferrite grains. The size of both is still submicroscopic. Troostite is softer and more ductile than martensite of the same carbon content.

Troostite is formed (a) from austenite at about 600 degrees Cent. on cooling at a rate too slow for the production of martensite but too fast for the production of sorbite, or (b) by reheating martensite to about 400 degrees Cent. The troostites formed by these means differ both in appearance and in properties. Troostite is characterized by a very rapid etcing rate.

Sorbite

An emulsion of cementite particles in Alpha iron. The size of the cementite particles and of the Alpha iron grains is larger than in troostite, the cementite particles just approaching visibility under the microscope. (Diameter on the order of 0.00001 inch.) Sorbite is softer and more ductile than troostite.

Sorbite may be formed on cooling austenite at a rate too slow for the production of troostite, or on reheating martensite or troostite to about 600 degrees Cent. There is again a difference in appearance and properties according to the manner of formation.

Granular Pearlite

Alpha iron containing rounded cementite particles large enough to be seen. The diameter of the cementite particles is ordinarily on the order of 0.0001 inch. The grain size of the Alpha iron is larger than in sorbite. Softer and more ductile than sorbite.

Fundamental Distinctions

From these definitions it will be seen that out of these five commonly recognized constituents there are only three fundamentally different types of structure:

1. Solid solution of carbon in Gamma iron.
   Austenite.
2. Atomic dispersion of carbon in Alpha iron.
   Freshly formed martensite.
3. Dispersion of cementite in Alpha iron.
   Aged or tempered martensite, troostite, sorbite, and pearlite.

Further distinctions are of degree and not of kind.

PROTECTIVE COATINGS FOR SELECTIVE CARBURIZATION

By J. S. Vanick and H. K. Herschman

Abstract

In a search for an effective protection of steel surfaces from carburization, coatings of copper plate and mineral base pastes, such as fireclay, kaolin and enamel mixtures were experimented with.

Copper plate is known to provide a very effective protection but it is subject to defects inherent in electrodeposits. These defects are most readily overcome by increasing the thickness of the coating. The thickness of plate necessary to protect surfaces against carburization was determined for comparatively long exposures. The methods used were somewhat more thorough than those heretofore reported in the literature. The data so obtained are shown in a chart and expressed by empirical curves for coating thickness and plating time.

Of the mineral base coatings, a thin coat of the enamel "ground coat" mixture and a thick coat of a fire-clay-sodium silicate paste provided moderately satisfactory protection. The ease with which the former is applied and the slightly better protection which it offered, added to its points of merit.

Microscopic evidence of nitrogen contamination and cementite concentration prompted a search for the source of the former and led to a discussion of the causes of the latter. An infiltration of nitrogenous gases through the protective coatings apparently caused the contamination by nitrogen although the decomposition of a nitrate was held responsible for similar effects in the specimens coated with the enamel mixture.

I. Introduction

IN THE carburizing process, it is often desirable to retain the softness, ductility or machinability of the original steel in certain areas of the carburized object. Carburization is accomplished by the penetration into the surface of the object of solid

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carbon or gaseous compounds of carbon. If the surfaces which are to be protected from carburization be insulated by a coating impermeable to the solid element or gaseous compounds of carbon, carburization cannot occur.

The need for data on protective coatings to be used in carburizing practice as applied to armor plate production which necessarily requires long periods of time induced the initiation of this investigation. However, in order that the scope of this work might include such information as may be applied to the more common commercial practices of carburizing, shorter intervals of time than employed in armor plate manufacture were also introduced.

Copper plate has a long record of service as a surface covering and it continues to be widely used. The process of copper plating is irksome, time-consuming and expensive. The surface which is to be plated must be free of dirt or grease, or the coating will lack either continuity or adherence. These disadvantages encourage efforts to develop other methods of protecting surfaces. Among the many ingenious methods which have been devised to accomplish this purpose, metal spraying and coating with mineral-base pastes seem to be most inviting.

Portevin[1] has described the application of the Schoop process of metal spraying to the formation of surface insulating coatings. A slight penetration of carburizing gases through this coating was reported but the diffusion of carbon into the underlying metal was insufficiently deep to be considered objectionable.

Various refractory coatings made up of earthy or mineral ingredients have achieved more or less success. The mineral ingredients are made into plastic pastes with water or sodium silicate as binders. Among these mixtures may be mentioned the alumina-sodium silicate and the asbestos sodium silicate pastes of Wood and McMullan;[2] copper-dust, emery-powder, sodium silicate paste of Galibourg and Ballay[3] and the enamel "ground coat" mixture subsequently described in this paper. Mixtures similar to those above are undoubtedly being used at present. Although comparative data resulting from competitive tests are not available a degree of impermeability which would be satisfactory for many purposes might be expected. The use of water or sodium

(1) *Comptes Rend.* Vol. CLXIII—1914, p. 1025.
(2) *Chemical and Metallurgical Engineering*, Vol. 26, p. 1077.
(3) *Revue de Metallurgie*, 1922. Vol. 19, p. 222.

silicate as binders for the solid particles would warrant the prediction of porosity. The volatilization of the water during heating or drying would create pores or passages for the evolved gas that would later be equally accessible to the entering gas. Coatings of the refractory type are not sufficiently impermeable for the more exacting demands that are frequently met in practice. Copper plate then becomes necessary.

II. Copper-Plate Coatings

There are few data available in regard to what should constitute an ample thickness of copper plate [4-5-6-7] particularly when long periods of carburization are necessary to produce the desired depth of case in the unprotected areas. In a survey of the literature on this subject, one is confronted with recommendations for coatings on such extreme delicacy as those obtained by momentarily washing or dipping the surface in copper solutions to those measuring 0.0005 to 0.001 inch in thickness which require a prolonged immersion in an electrolytic plating bath.

Although the copper cyanide bath is most generally used for the deposition of such protective coatings as referred to, there are some cases in which a copper cyanide flash followed by a deposit of copper from a copper sulphate bath have been recommended. The information available on the types of plate deposited from a sulphate bath tend to indicate that they are less impervious than those obtained from a cyanide solution, and that therefore a greater thickness is required.

At carburizing temperatures with the assistance of impurities at the copper-iron junction, copper may diffuse into the steel and very thin films may be completely absorbed or possibly "coalesced" into a thickened network by which process such areas would become exposed.

The gaseous compounds of carbon, oxygen, hydrogen and nitrogen which constitute the carburizing gas are doubtless soluble to some extent in hot copper. Hence diffusion of the car-

(4) See Lathrop, *Transactions*, American Society of Mechanical Engineers, Vol. 24, 1912, p. 971.

(5) Zimmerli, E. P., *Transactions*, American Society of Mechanical Engineers, Vol. 42, 1920, p. 566.

(6) Thain, W. A., *Transactions*, Faraday Society, Vol. 16, p. 478, 1920-21.

(7) Maeder, R. E., American Electroplaters Society, Vol. 9, No. 11, p. 5, 1922.

burizing gases through the electrodeposited copper might be expected. Pilling[8] has presented data showing the relatively rapid rate at which hot reducing gases penetrate commercial copper. An appreciable retardation of the diffusion rate through the electrodeposited material would be expected on account of the absence of oxide films and globules which upon reduction create intergranular fissures and voids in ordinary copper. The total infiltration from the above causes would be relatively small. Most of the permeability of the thicker coatings would be traceable to defects inherent in electrodeposits. Imperfections in the copper coating, such as pin holes, pores, embedded inclusions, imperfect adherence, etc., are common defects. These imperfections may be overcome by applying thicker films of copper plate, which will insure the coated surface against carburization.

Table I
Thickness of copper coatings

—Estimated—		—Measured—	
mm.	inches	mm.	inches
0.00127	.00005	0.00119	.000047
0.00254	.00010	0.00213	.000084
0.0064	.00025	0.00674	.000265
0.0127	.00050	0.0129	.000509
0.0193	.00075	0 0182	.000723
0.0254	.00100	0.0275	.001084
0.0381	.00150	0.0318	.001252
0.0508	.00200	0.0541	.002128
0.0762	.00300	0.0766	.003012

Materials and Methods of Procedure

Specimens approximately 5/8-inch square and 1 inch long, were machined from Armco iron slabs and the surfaces finished by grinding. Before plating, the specimens were scrubbed with powdered pumice stone and water, then immersed as cathodes in an electrolytic cleaning bath consisting of a solution of sodium cyanide and sodium carbonate through which a sufficiently high current was passed to produce a vigorous evolution of hydrogen on the cathodes. After washing with distilled water, the specimens were copper plated at a current density of about 0.5 amp/dm^2 (4.7 amp/sq. ft.) in a cyanide bath* which was maintained at 50-60 degrees Cent. Plating was continued for a predetermined interval of time which

(8) *Transactions*, American Institute of Mining and Metallurgical Engineers, 1921, Vol. LX, p. 322.

*Plating solution consisted of copper cyanide, 22.5 gr. Liter; sodium cyanide, 30 gr. Liter; sodium carbonate, 15 gr. Liter.

had been estimated to produce the desired thickness of coating, upon the arbitrary assumption that the cathode efficiency was 65 per cent.

The estimates of coating thickness were checked by measurements of deposits on specimens selected for this purpose. As is quite generally known, more metal is deposited on the edges, corners, or sharp angles of a plated object than on smooth, plane surfaces. For this reason, microscopic measurements of coating thickness were made at the center of each rectangular face of the specimen. The results appear in Table I.

The resistance of the various thicknesses of copper plate, to penetration by carburizing gases was determined by the following experimental procedure:

A. Groups of specimens comprising six thicknesses of coating were exposed for different intervals of time increasing in 12-hour steps, from 12 to 72 hours.

B. Six thicknesses of coating equal to those of A, were given a single exposure of 72 hours in six different carburizers.

C. Thin coatings were exposed for intervals of time within the 1½ to 48-hour range to include commercial practice and check results of A.

For a carburizing compound with a reproducible composition a mixture of 40 per cent charcoal, 40 per cent barium carbonate and 20 per cent dry bone was used. For the 72-hour exposure in different carburizers, the compounds used were the one above, a modification of it consisting of 40 per cent charcoal, 20 per cent barium carbonate and 40 per cent dry bone and 4 commercial mixtures.

Specimens were packed in small carburizing boxes with an inch or more of the carburizing compound adjoining the specimen surface. The boxes were sealed with a fire-clay mixture, charged into a cold furnace, brought up to the carburizing temperature of 925 per cent Cent. (1700 degrees Fahr.) held for their respective carburizing periods and then withdrawn and allowed to cool in air.

Examination and Results

A visual inspection of the specimens after carburization, showed that in general, the copper adhered quite firmly. The

thicker coatings as one would expect, were better able to maintain their adherence, coherence, continuity and initial appearance.

To determine the permeability of the various thicknesses of copper plate and the microscopic condition of the coating, specimens were plated with a coat of nickel, sectioned longitudinally, polished and examined. To evaluate the merits of the several

Table II-a
Resistance of increasing thicknesses of copper plate to penetration by carburizing gas

Spec. No.	Coating thickness Inches	mm.	Exposure in hours	Carbon Penetration Total depth mm.	Max. conc. % C.	Depth of penetration to 0.20 C. mm.	Appearance* of coating after exposure
1	.00025	.0064	12	.775	.02	. . .	Fair
2	.00025	.0064	24	2.26	.33	.70	Poor
3	.00025	.0064	36	1.87	.40	.78	Poor
4	.00025	.0064	48	3.58	.77	2.19	Good
5	.00025	.0064	60	4.90	.87	2.57	Poor
6	.00025	.0064	72	7.31	.87	4.43	Poor
12	.00050	.0127	12	0.0	. .	. .	Fair
13	.00050	.0127	24	.86	.04	. .	Poor
14	.00050	.0127	36	0.0	. .	. .	Fair
15	.00050	.0127	48	2.10	.17	. .	Fair
16	.00050	.0127	60	2.33	.40	.78	Poor
17	.00050	.0127	72	2.72	.37	1.47	Poor
23	.001	.0254	12	0.0	. . .	. .	Fair
24	.001	.0254	24	0.0	. .	. .	Fair
25	.001	.0254	36	0.0	. .	. .	Fair
26	.001	.0254	48	1.94	.10	. .	Poor
27	.001	.0254	60	.94	.05	. .	Poor
28	.001	.0254	72	4.42	.50	. .	Poor
34	.0015	.0381	12	0.0	. . .	. .	Good
35	.0015	.0381	24	0.0	. . .	. .	Fair.
36	.0015	.0381	36	0.0	. . .	. .	Good
37	.0015	.0381	48	0.0	.	.	Good
38	.0015	.0381	60	0.0	.	.	Good
39	.0015	.0381	72	2.33	.13		Poor
45	.002	.0508	12	0.0		. .	Good
46	.002	.0508	24	0.0	.		Fair
47	.002	.0508	36	0.0	.		Fair
48	.002	.0508	48	0.0			Poor
49	.002	.0508	60	0.0	.		Fair
50	.002	.0508	72	0.0	.	.	Good
56	.003	.0762	12	0.0	. . .	. . . .	Good
57	.003	.0762	24	0.0	.		Good
58	.003	.0762	36	0.0	.		Poor
59	.003	.0762	48	0.0	.		Good
60	.003	.0762	60	0.0	. . .		Poor
61	.003	.0762	72	0.0	.		Good

*Condition of coating:
Good—unaltered after exposure.
Fair—small localized fusions of Cu and Fe or small blisters on surface.
Poor—large localized fusions of Cu and Fe or numerous blisters on surface.

thicknesses of coating, the total depth to which the carbon had penetrated was measured, the concentration of carbon at the surface was estimated and the depth at which a concentration of 0.20 per cent carbon appeared, was determined. The results are listed in Tables IIa, IIb and III.

The initially low concentration of carbon in Armco iron reduces the difficulty of measuring the depth of the carburized zone

and estimating the carbon concentration. Having determined the rate of migration of carbon into iron under identical conditions, the data so obtained could be linked with those of Tables II and III for the purpose of interpreting the effectiveness of a coating. A close relation would be expected between the total depth of the penetration of carbon and the period of time dur-

Table II-b

Resistance of increasing thicknesses of copper plate to gases produced by various carburizers

Period of Test; 72 hours

Spec. No.	Coating Thickness Inches	mm.	Carburizer	Carbon Penetration Total depth mm.	Max. conc. % C.	Depth of penetration to 0.20 C. mm.	Appearance of coating after exposure	Remarks
6	.00025	.0064	A	7.31	.87	4.43	Poor	
7	.00025	.0064	B	4.20	.15		Poor	N
8	.00025	.0064	C	4.36	.50	1.79	Poor	n
9	.00025	.0064	D	3.11	.08		Poor	N
10	.00025	.0064	E	1.87	.08		Poor	n
11	.00025	.0064	F	4.98	.25	.78	Poor	N (n) v
17	.00050	.0127	A	2.72	.37	1.47	Poor	
18	.00050	.0127	B	4.13	.27	1.02	Poor	N
19	.00050	.0127	C	3.61	.40	1.29	Poor	N
20	.00050	.0127	D	2.33	.25	.62	Fair	n (heavy) v
21	.00050	.0127	E	1.70	.05		Poor	
22	.00050	.0127	F	3.11	.08		Poor	
28	.001	.0254	A	4.42	.50	1.55	Poor	
29	.001	.0254	B	4.65	.18		Poor	N
30	.001	.0254	C	1.94	.05		Poor	N
31	.001	.0254	D	2.32	.10		Fair	
32	.001	.0254	E	....	.00		Poor	
33	.001	.0254	F	.72	.03		Fair	
39	.0015	.0381	A	2.33	.13		Poor	
40	.0015	.0381	B	1.55	.02		Fair	
41	.0015	.0381	C	2.25	.08		Polr	
42	.0015	.0381	D	1.47	.02		Fair	
43	.0015	.0381	E	....	.00		Poor	
44	.0015	.0381	F	....	.00		Fair	
50	.002	.0508	A	....	.00		Good	
51	.002	.0508	B	.09	.20		Good	
52	.002	.0508	C	....	.00		Poor	
53	.002	.0508	D	....	.00		Fair	
54	.002	.0508	E	....	.00		Poor	
55	.002	.0508	F	....	.00		Poor	
61	.003	.0762	A	....	.00		Poor	
62	.003	.0762	B	....	.00		Good	
63	.003	.0762	C	....	.00		Good	
64	.003	.0762	D	....	.00		Good	
65	.003	.0762	E	....	.00	....	Good	
66	.003	.0762	F	....	.00	....	Good	

N—heavy penetration of large nitride needles, as illustrated in Fig. 7a and b.
n—penetration of small nitride needles, as illustrated in Fig. 6f.

ing which carburizing gases were in contact with the surface. By this method an estimate of the time of failure of the coating might be made. Similarly, the concentration of carbon at the surface would afford an index much less reliable, however, of

either the relative magnitude of the perforations or the chemical character of the gas which they admitted.

For example, specimens 1 to 6 of Table IIa, show an expected increase in depth of case, indicating a failure of the coating in less than 24 hours. Similarly a high concentration of carbon near the surface would indicate a comparatively porous and permeable coating and suggest a hydrocarbon rather than oxy-carbon infiltration.(9)

The data of Tables II-a and III, plotted with respect to the depth to which carbon had penetrated the coated specimens appear in Fig. 2. For carburizing periods of less than 36 hours, the increment of coating thickness for zero penetration decreases, then sharply increases for the 60 and 72-hour periods. It is readily apparent that the plotted points do not closely follow

Table III
Resistance of very thin copper coating to penetration

Specimen No.	Carburizing Period in hours	Carburizer	Thickness Copper Coating Inches	Thickness Copper Coating mm.	Carbon Penetration Total depth mm.	Carbon Penetration Per Cent concentration	Carbon Penetration Depth of penetration to 0.20 C. mm.	Remarks
100	1½	A	.00005	.00127	....	0.16	0.98	
101	3	A	.0001	.00254	....	0.02	0.32	
102	6	A	.0002	.00508	....	0.00	....	
103	12	A	.00005	.00127	0.39	0.87	0.63	
104	12	A	.0001	.00254	....	0.06	0.84	
105	12	A	.0002	.00508	....	0.06	0.88	
106	21	A	.0005	.0127	....	0.00	....	
107	24	A	.00005	.00127	0.85	0.76	2.28	
108	24	A	.0001	.00254	....	0.12	1.16	
109	36	A	.0005	.0127	....	0.02	....	Partial
110	48	A	.00075	.0191	....	0.00	....	penetration

the straight lines, but tend to become asymptotic to the coating thickness abscissa; a relation suggesting an infinite coating thickness for very long carburizing periods. In view of this, the lines for carburizing periods exceeding 48 hours, were drawn to average the position of the determined points and the values at their intersections with the "thickness of coating" line were taken as impermeable thicknesses of coating. If these values for zero penetration be plotted, a curve roughly paralleling one for "velocity of carbon migration" is obtained. The parallelism of the two suggests a relation between the time of exposure and the activity of the gases in the carburizing chamber; a relation wherein the added activity of the gas requires the additional thickness of coating.

(9) Giolitti; Cementation of Iron and Steel, McGraw Hill Co., p. 131.

Using the values for coating thickness taken from the intersections of the time curves with the zero penetration abscissa of Fig. 2, the curves of Fig. 3 were prepared.* From this diagram the plating time necessary to deposit an adequate thickness of coating for the conditions indicated may be rapidly determined by reading the abscissa for the selected carburizing period ordinate.

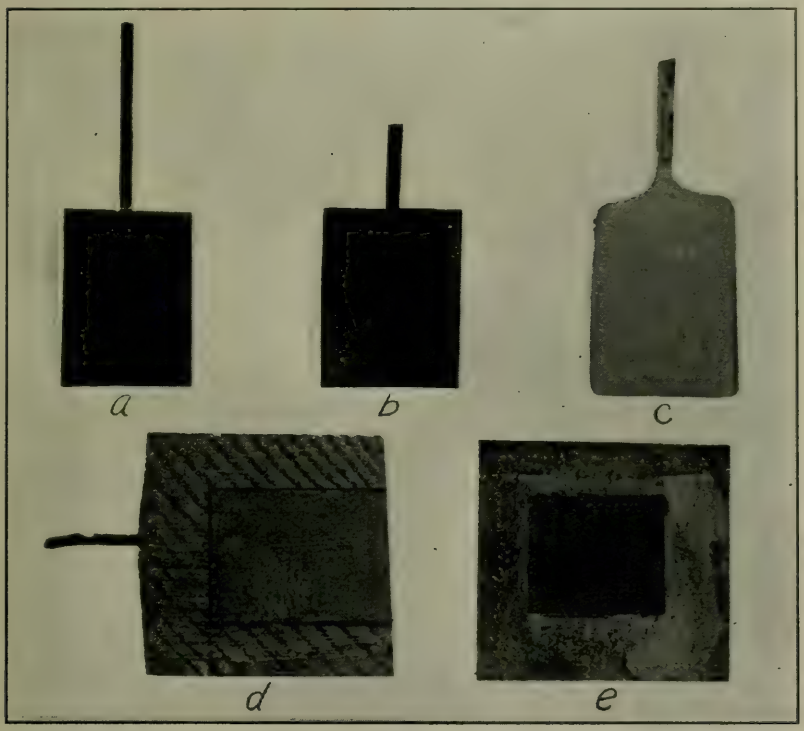

Fig. 1—Appearance of coated specimens. Natural size. a. Armco iron. b. Copper coating. c. Ground coating. d. Kaolin coating. e. Bottom view of d.

A 72-hour endurance test of the several thicknesses of copper was made by exposing coated specimens in six different carburizers. The results appear in Table II-b. The data show that a large difference in depth of penetration may be expected for the individual penetrable thicknesses of coating. The intersection for zero penetration corresponds to the one recorded in Fig. 2.

*Credit is due M. R. Thompson, chemist, Bureau of Standards, for this work.

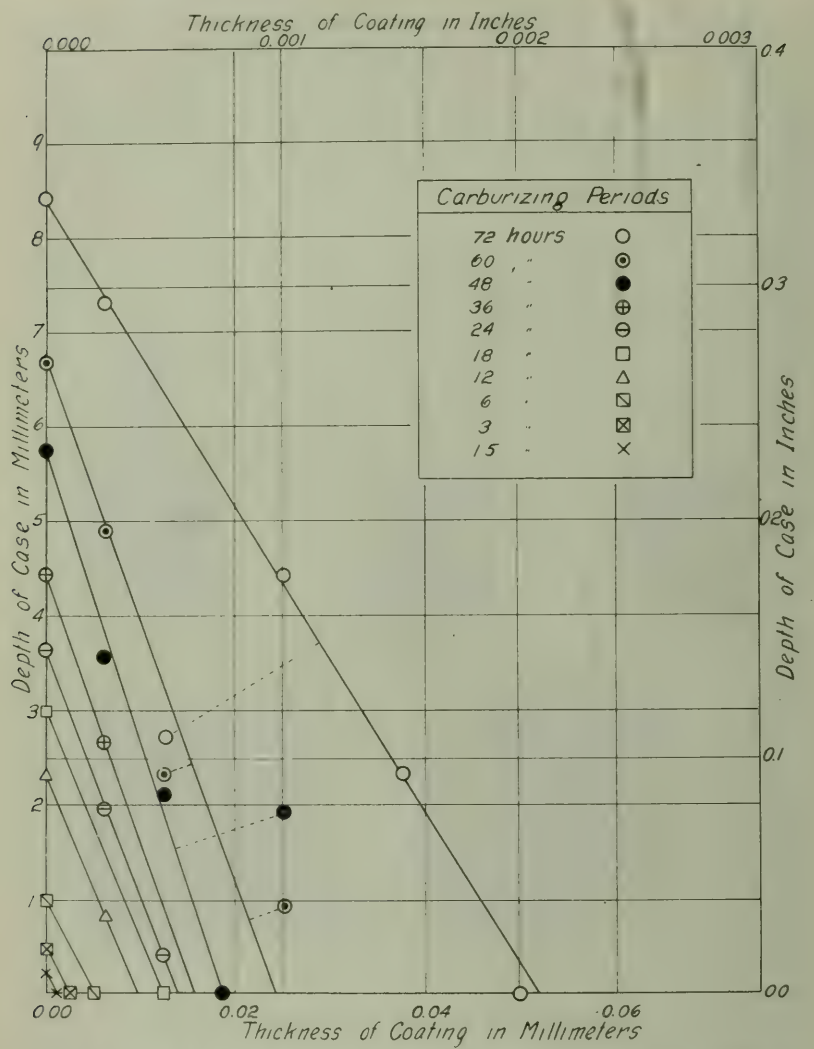

Fig. 2—Depth of carbon migration versus copper coating thickness. Intersection of carburizing period lines with base line is interpreted as safe thickness.

Some of the alkali-earth carbonates which are essential ingredients of many solid carburizers might be expected to corrode the coating surfaces at carburizing temperatures. The decomposing semifused salts might generate corrosive products in the nitrogen-hydrogen-carbon gases which would attack the coating

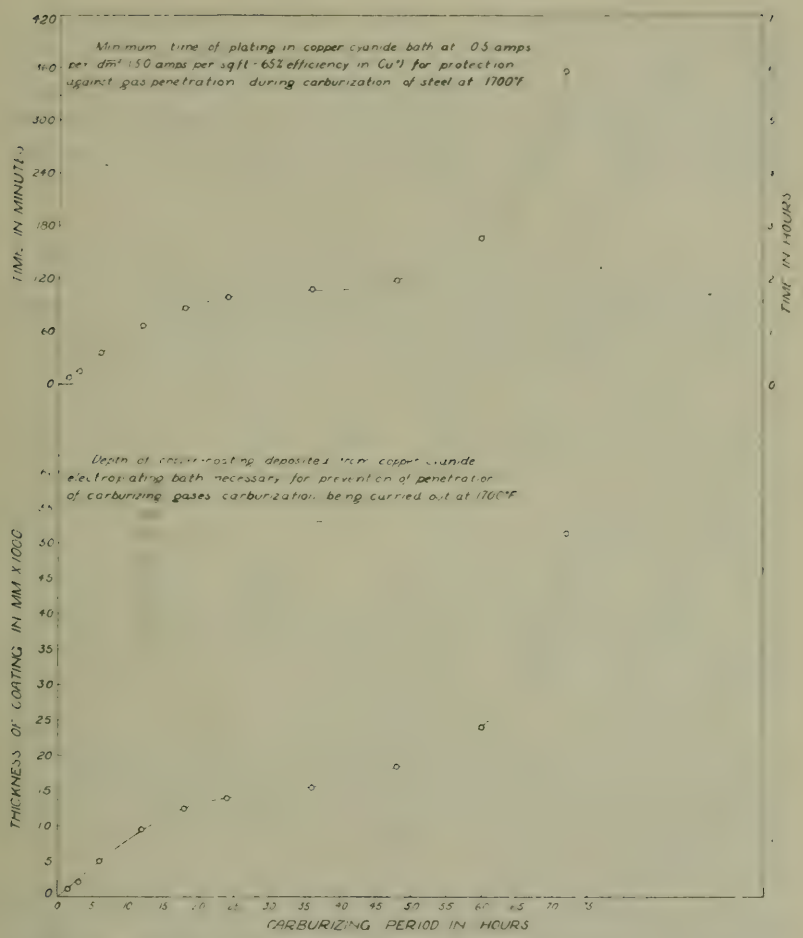
Minimum time of plating in copper cyanide bath at 0.5 amps per dm² (50 amps per sq ft - 65% efficiency in Cu°) for protection against gas penetration during carburization of steel at 1700°F
Depth of electroplating deposited from copper cyanide electroplating bath necessary for prevention of penetration of carburizing gases carburization being carried out at 1700°F
TIME IN MINUTES
TIME IN HOURS
THICKNESS OF COATING IN MM X 1000
CARBURIZING PERIOD IN HOURS

Fig. 3—Plating time and thickness of coating expressed for various carburizing periods.

surfaces. Although an appreciable difference in the relative appearance of the coatings was observed the degree of destruction varied for the individual carburizers and a distinction could not be made.

Most of the data listed in Table III were obtained by running a check test on the penetration of carbon through coatings expected to be either permeable or impermeable as calculated from Fig. 3. Where a penetrable thickness was used, an infiltration of gases had occurred; where an impenetrable thickness was used,

no carburization took place. The values for concentration of carbon and depth of case for penetrable coatings varied somewhat from those of Table II-a. In this and the preceding groups of specimens evidence of the infiltration of nitrogenous gases was observed. These observations will be discussed in a subsequent description of the microstructural features.

III. Mineral Base Coatings

The success of certain coatings made of single or mixed minerals is mentioned in the introduction to this article. Usually mineral-base coatings depend upon water or sodium silicate to float them or provide them with the plasticity necessary for their application. The evaporation of the water and the decomposition of the sodium silicate during drying or heating generally renders the resulting coating more or less porous; the porosity depending upon the amount of volatile material held in the plastic mass. The ability of such coatings to prevent carburization, depends upon their thickness and the mechanical obstruction which an intricate aggregate of fine particles offers. Other properties, such as adherence, coherence, density and continuity would undoubtedly vary with the composition of the coatings and the physical properties of their ingredients.

Fire-clay has served and continues to serve the purpose of a coating for preventing carburization, but its shrinkage upon drying or baking causes large surface cracks and its poor adherence may induce parting along the contact of the steel with the refractory surfaces.

In a search for a more impermeable coating, sodium silicate was substituted for water in the fire-clay mixture in order to reduce the shrinkage and improve the adherence; a mixture of kaolin made plastic with sodium silicate was also chosen because of the finely divided condition of the kaolin, and an enamel "ground coat" which would flux at the temperature of carburization was selected with the expectation that improved adherence, coherence, continuity and density would be achieved when this mixture was baked or burned at the carburizing temperature.

Materials, Method of Preparation and Test

The fire-clay and kaolin coatings were made up by adding

sodium silicate to the dry powder and stirring to the consistency of clay or stiff mud. The plastic mass was then securely packed around the specimens with the aid of a retaining mold and finally dried. The shrinkage of the coatings during drying produced concave surfaces which were flattened to a uniform thickness of 5/16 inch on each of the sides of the specimen.

The enamel "ground coat" required much more attention. "Ground coats"[10-11] find application in the enameling process where they serve as the bond between the metal and the glazed finish. The mixture chosen for its fusibility and adherence in the carburizing temperature range was prepared and applied as follows*:

Composition	Parts by weight	
Flint (SiO_2)	70	Frit
Borax	37	
Sodium nitrate†	7	
Lead oxide (Pb_3O_4)	8	
Frit	100	Mill mix
Clay (J & P)††	93	

The mixture-called frit, was sintered at 850 to 900 degrees Cent. (1565 to 1650 degrees Fahr.) and the resulting sinter crushed and sieved. Clay was added to the sinter to form the "mill mix" and the mixture wet-ground in a ball mill. Enough water was added to give the finished product the consistency of an enamel or thickened paint. An excess of water would do no harm if the mixture were allowed to stand because the excess would separate from the suspensoid and could be decanted.

Before applying this coating, the specimens were cleaned of grease, pickled in a 10 per cent nitric acid-alcohol solution, washed in alcohol and dried. The coating was applied by immersing the specimens in the emulsion, then draining and drying them.** The latter procedure was repeated 2 or 3 times to obtain a coating approximately 3/32 inch thick. The coated specimens are illustrated in Fig. 1.

The mineral coated specimens were put through the same experimental procedure as the copper-coated specimens. This

(10) See *Transactions*, American Ceramic Society, 18, 1916, p. 343.
(11) See *Transactions*, American Ceramic Society, I, 1918, p. 99.
*The selection and preparation of this ground coat mixture was directed by R. R. Danielson, formerly of the Bureau of Standards.
†Sodium nitrate was later replaced by sodium carbonate after the presence of nitrogen, probably introduced during the decomposition of nitrate in the presence of carbon, had been observed.
††A special enamel clay obtained from Johnson and Porter of McKenzie, Tenn., and known as "number eleven" clay.
**Irregular surfaces could be coated by brushing or spraying.

procedure consisted of a 72-hour exposure sampled at 12-hour intervals and a 72-hour exposure in one of 6 carburizing compounds. An additional adherence test of the "ground coat" consisted of exposures up to 72 hours, of smoothly finished specimens of 1/16, 1/8 and 1/4-inch radius covered with the coating which was applied as described above. This test was made to determine the feasibility of applying the coating to surfaces ma-

Table IV-a
Resistance of mineral coatings to penetration by carburizing gases.

Spec. No.	Coating Material	Thickness Inches	Thickness mm.	Exposure in hours	Carbon Penetration Total depth mm.	Max. conc. % C.	Depth of penetration to 0.20 C. mm.	Remarks
67	Kaolin	.3125	7.94	12	1.55	.12	. . .	
68	Kaolin	.3125	7.94	24	2.48	.55	.93	
69	Kaolin	.3125	7.94	36	4.34	.78	2.32	
70	Kaolin	.3125	7.94	48	5.19	.65	1.76	
71	Kaolin	.3125	7.94	60	5.04	.75	1.86	
72	Kaolin	.3125	7.94	72	6.99	.87	2.64	
78	Fire Clay	.3125	7.94	12	1.55	.17	. . .	
79	Fire Clay	.3125	7.94	24	2.01	.12	. . .	
80	Fire Clay	.3125	7.94	36	3.57	.17	. .	
81	Fire Clay	.3125	7.94	48	3.72	.15	. .	
82	Fire Clay	.3125	7.94	60	3.78	.20	. .	
83	Fire Clay	.3125	7.94	72	3.36	.40	2.94	
89	Enamel—	3 coats		12	1.37	.10	. .	n
90	Ground coat	3 coats		24	2.02	.08	. .	n
91	Ground coat	3 coats		36	3.26	.13	. . .	n
92	Ground coat	3 coats		48	3.65	.17	. . . .	n
93	Ground coat	3 coats		60	4.65	.06	. . .	n
94	Ground coat	3 coats		72	5.90	.13	. . .	n

n—presence of smal nitride needles apparently caused by the decomposition of sodium nitrate which was an ingredient of this coating.

chined to a smooth finish by grinding and filleted to the usual dimensions encountered in practice.

Examinations and Results

An inspection of the specimens following their exposure to the carburizing gases showed that the kaolin coatings had cracked badly and appeared porous; the fire-clay coatings appeared equally porous, but had not cracked; the "ground coat" coatings had flaked from the surfaces because of the difference in the rate and magnitude of the contraction of the steel and coating, during cooling. Isolated patches of the "ground coat" remained partly fused to the surfaces. These particles were removed by a light tapping or impact. The fragments appeared compact and dense.

A microscopic examination of cross sections of the speci-

mens yielded the data listed in Tables IV-a, IV-b and IV-c. A survey of these data clearly shows the permeability of the kaolin coating. An appreciable depth of penetration is accompanied by a high concentration of carbon at the surface. The fire-clay coating shows a more shallow penetration and a lower carbon concentration. The limited porosity and sustained resistance to pen-

Table IV-b
Resistance of mineral coatings to gases produced by various carburizers.
Period of test; 72 hours

Spec. No.	Material	Coating Thickness Inches	mm.	Carburizer	Carbon Penetration Total depth mm.	Max. conc. % C.	Depth of penetration to 0.20 C. mm.	Remarks
72	Kaolin	.3125	7.94	A	6.99	.87	2.64	
73	Kaolin	.3125	7.94	B	6.20	.85	2.48	
74	Kaolin	.3125	7.94	C	5.80	.37	2.17	n (heavy)
75	Kaolin	.3125	7.94	D	6.33	.55	2.89	n (heavy)
76	Kaolin	.3125	7.94	E	4.55	.55	2.15	n (heavy)
77	Kaolin	.3125	7.94	F	6.20	.87	2.95	n (heavy)
83	Fire Clay	.3125	7.94	A	3.36	.40	2.94	
84	Fire Clay	.3125	7.94	B	7.75	.40	2.79	N
85	Fire Clay	.3125	7.94	C	4.03	.20		
86	Fire Clay	.3125	7.94	D	5.58	.20		
87	Fire Clay	.3125	7.94	E	3.59	.32	2.04	n
88	Fire Clay	.3125	7.94	F	3.95	.08		
94	Enamel	3 coats		A	5.90	.13		n
95	Ground coat	3 coats		B	4.65	.17		N (heavy)
96	Ground coat	3 coats		C	5.43	.25	.78	N (heavy)
97	Ground coat	3 coats		D	5.89	.33	2.48	N
98	Ground coat	3 coats		E	6.05	.30	1.55	N (heavy)
99	Ground coat	3coats		F	5.82	.12		n

n—presence of small nitride needles.
N—presence of large nitride needles.

etration of the "ground coat" is expressed in the deep, low-carbon penetration which suggests a continuous, but feeble infiltration of gas.

In the adherence test of the "ground coat," smoothly ground surfaces of ¼, ⅛ and 1/16-inch radius were coated with the mixture. The coating failed to adhere to the smooth surfaces and deep penetrations resulted from the 24-hour exposure as shown in Table IV-c. The test shows that a surface roughend to a dull or matte finish by pickling or other means, is necessary to provide an anchorage for the contact films of the coating. In other respects, the "ground coat" of the thickness used, appears satisfactory where a slight penetration is permissible. Where none is permissible, recourse to the copper coating seems necessary.

IV. Incidental Features

Microstructure

In the critical examination of a large number of specimens, features of more or less importance are quite likely to present themselves for such attention as the urgency of the principal investigation may allow. In the present work, the occurrence of

Table IV-c
Exposure of smoothly finished, short radius specimens, coated with "ground coat."

Specimen No.	Carburizing	Carbon Penetration Total	Max. Con. C.	Depth of penetration	Remarks
1/8" radius	Depth mm.	% C.	% C.	to 0.20% C.	Penetration
1	3	1.02	.18		Uniform
2	6	1.68	.75		Irregular
3	12	complete	1.0	.98	Uniform
4	18	no specimen			Uniform
5	24	complete	1.0		Uniform
6	36	complete	1.0		Uniform
7	48	complete	1.2		Uniform
8	60	complete	1.1		Uniform
9	72	complete	1.2		Uniform
1/4" radius					
1	3	1.02	.32	....	Uniform
2	6	1.26	.40	.77	Uniform
3	12	2.22	.87	1.30	Irregular
4	18	2.73	.55	1.54	Irregular
5	24	complete	.90	....	Uniform
6	36	complete	.90	....	Uniform
7	48	complete	1.10	....	Uniform
8	60	complete	.90	....	Uniform
9	72	complete	1.20	....	Uniform
1/4" radius					
1	3	.84	.18	....	Uniform
2	6	1.19	0.36	0.49	Uniform
3	12	1.82	0.55	0.70	Irregular
4	18	no specimen	....	....	
5	24	2.88	.90	1.16	Irregular
6	36	3.64	.90	2.14	Irregular
7	48	4.32	1.00	2.59	Irregular
8	60	4.90	1.00	2.80	Irregular
9	72	5.30	1.10	2.80	Irregular

thick cementite films and evidence of the infiltration of nitrogenous gases warranted more than passing attention. The presence of either of these two components of structure is often accompanied by brittleness or spalling in the zones they occupy; an undesirable feature for many types of service. Fortunately this structure did not exceed 2 or 3 millimeters of depth and would not be considered injurious if the metal below the coated surface were subsequently removed. In industrial practice, steels for carburizing purposes, usually contain a small amount of carbon which acts as a more or less effective buffer against the infiltration of nitrogenous gases thereby reducing the degree of contamination.

Figs. 5-a and 5-c illustrate the form in which the deposited carbon is concentrated beneath the coated surface in cementite films or white bordered patches of pearlite. The susceptibility of the specimens to contamination by nitrogen and the resemblance of the white bordered patches of pearlite to corresponding "nitride" patches prompted the application of an etching test

Fig. 4—Examples of good and poor coatings. a. Satisfactory copper coating. b. A local fusion of copper and iron. Mag. x 100. Etched in 2 per cent nitric acid in alcohol.

to assist in the identification of the patches. The failure of Steads reagent and the success of sodium picrate in darkening the bright edges, as illustrated in Fig. 5-d indicated that cementite predominated rather than nitride. The structure presented in Figs. 5-a and 5-c prevailed when the average carbon content estimated from the total area occupied by the patches of pearlite, did not exceed 0.10 per cent. The initially low carbon content of the Armco iron and the slow cooling in the carburizing boxes doubtless assisted in producing this particular structure. There are possibilities that other causes such as the presence of oxides or oxygen in the iron or the preferential infiltration of carbon-rich, hydrocarbon gases through the protective coating, encouraged the concentration of carbon.

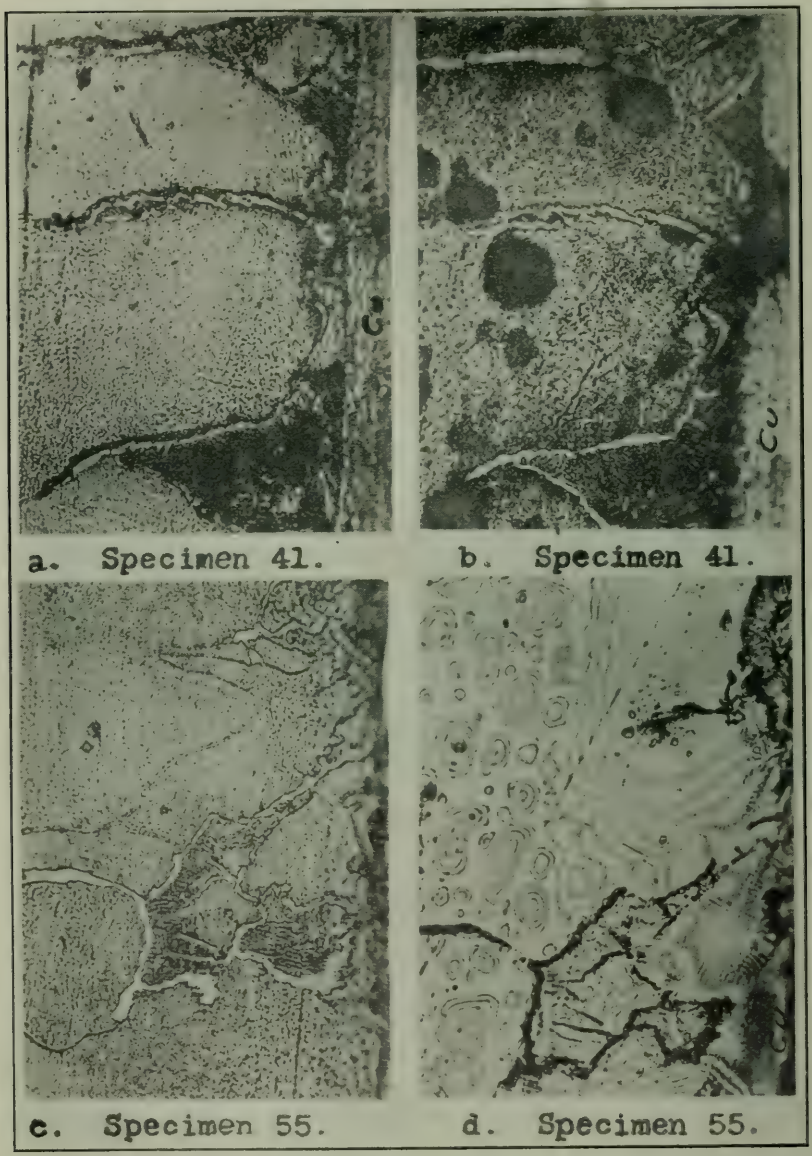

Fig. 5 Etching tests of "white bordered" pearlitic patches. a. Infiltration of hydrocarbon gases probably produces heavy cementite films. Fig. b (etched with Stead's reagent) fails to darken white border of patches. Fig. d etched with boiling sodium picrate; cementite edge is darkened. a and c etched with 2 per cent HNO_3 in alcohol. × 500 dia.

The presence of long and short "nitride" needles in the subsurface layer of many of the specimens clearly demonstrated that an increase in the nitrogen content of this zone had occurred. The nitrogen markings cannot be detected in eutectoid or hypereutectoid areas. For this reason the hypoeutectoid zones containing less than 0.45 per cent carbon offered the best matrix for the detection of nitrogen. The structures presented in Figs. 6 and 7 show the distinctive characteristics of nitrogen bearing areas. Armco iron possesses an initial nitrogen content of 0.003 to 0.0055 per cent. The structure of the original material is reproduced for convenient reference in Fig. 6-a. If a surface be roughened by etching more deeply than is necessary to develop the grain outline a number of small cuts or a few large slashes such as appear in Figs. 6-b and 6-c, may be disclosed. These markings closely resemble isolated nitride needles but beyond this resemblance, evidence to establish their identity is lacking. Etching in Stead's reagent darkened those of Fig. 6-c, although this test might be discounted because the thin needles are too delicate to be insensitive to corrosive reagents. An analysis for nitrogen of a layer, 1 mm. thick, cut from specimens showing the types of structure illustrated in Figs. 6-b and 6-c, yielded identical results. An increase in local concentration probably produces the coarser needle.*

Figs. 6-d, e, f and 7-a, b, show an unmistakable increase in the number of nitride markings which indicates an increase in nitrogen in the subsurface layers. Some of the unusual positions which these markings adopt may be worth mentioning. In Fig. 6-d, for example, the usual intercleavage alignment assumes a directional trend that makes the small needles resemble elongated etching pits. However, the multivariant* orientation of the markings of Fig. 6-f, in an adjoining area destroys the etching pit requirement of "uniformity of orientation in individual grains." The markings within the large grain of Fig. 6-f adopt a tandem arrangement that appears to outline several small grains which have coalesced to form the large individual; the small needles exhibiting a preference for the poorly knit contacts of the precoalesced units.

*In the nitrogenization of iron with ammonia, through a temperature gradient, small, thin needles have been found in low temperature areas which yielded less nitrogen than areas containing large needles.

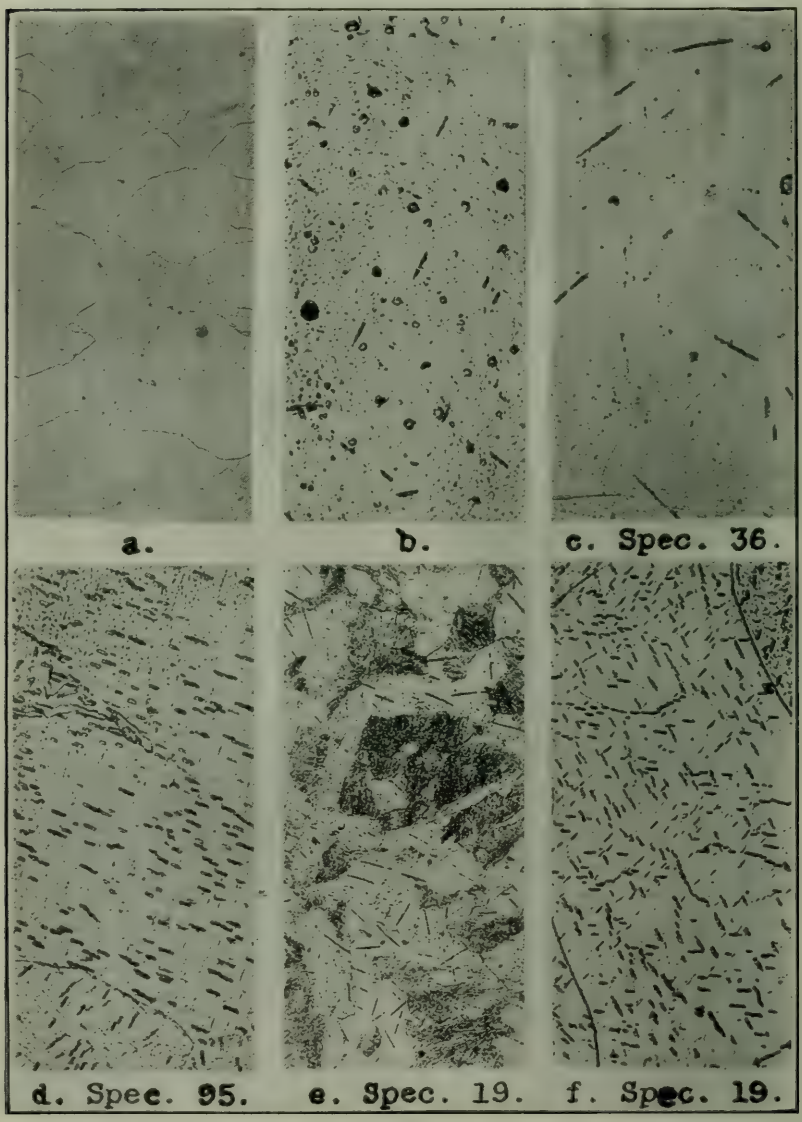

Fig. 6—Microstructural evidence of nitrogen contamination. a. Original structure of Armco iron. b. Suggestion of a small initial content of nitrogen in short, widely separated "needles." c. Local concentration of nitrogen indicated larger nitride needles. d. Heavy precipitation of small needles. e. Large and small needles mixed with pearlitic matrix in copper coated specimens. f. A ferritic area of Figs. b, c, d and f, x 500. Others x 100 dia. Etched in 2 per cent nitric acid in alcohol.

Figs. 7-a, b and c illustrate the unusual phenomena of nitride needles traversing patches of pearlite. The intersections seem to be confined to the ferrite laminations. The small markings appear to adopt a latticed spacing within the ferrite that is

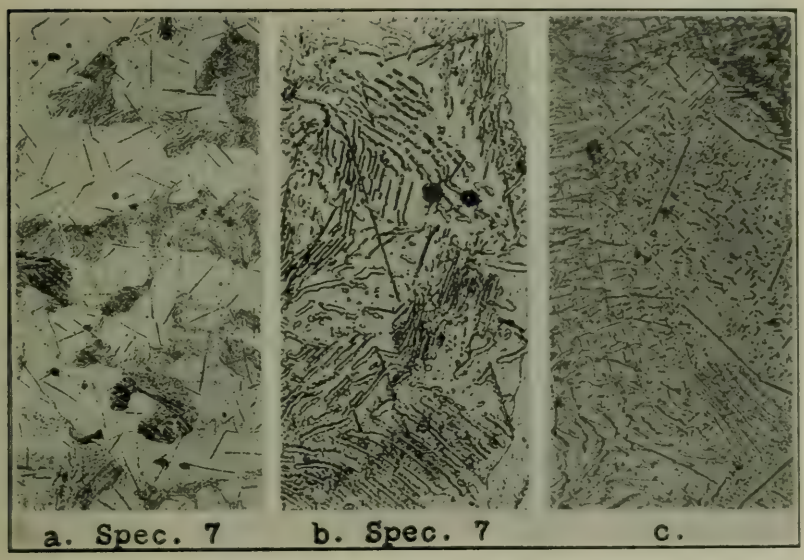

Fig. 7—Pearlitic areas contaminated by nitrogen. a. Large nitride needles indicate infiltration of compounds of nitrogen. Needles appear along cleavage planes and grain boundaries. b. Needles appear in pearlitic patches but do not intersect cementite lamellae. c. Large and small needles appear in pearlitic areas. All etched with 2 per cent HNO_3 in alcohol. a x 100. b and c x 500.

sandwiched between sheets of pearlite. Fig. 7-c shows large and small needles scattered through a pearlitic area. In all specimens the large needles as shown in Figs. 6-c, 7-a and 7-b, are found near the edges, frequently intermingled with the small needles, while the latter alone prevail in the more remote areas of the affected layer.

Source of Nitrogen Contamination

In view of the microscopic evidence of the presence of nitrogen the problem of determining the source of this contamination was presented. The nitride structures may have been due to:

(a) A surface-ward migration of nitrogen initially dissolved in the specimen.

(b) A transfer from the coatings of nitrogen originating from occluded gas or decomposed ingredients.

(b) A transfer from the coatings of nitrogen originating burizers through the coatings.

Table V.
Nitrogen content in 1 mm. layer underlying copper coating.

Spec. No.	Carburizer	Coating inches	Coating mm.	Exposure in hours	% Nitrogen in 1 mm. layer	Approx. multiple of initial N content	N microscopically observed
12	A	.0005	.0127	12	.0070	1.3	No
13	1.24%N.	.0005	.0127	24	.0070	1.3	No
14		.0005	.0127	36	.0070	1.3	No
15		.0005	.0127	48	.0130	2.4	No
16		.0005	.0127	60	.0130	2.4	No
17		.0005	.0127	72	.0100	1.8	No
45	A	.0020	.0508	12	.0034	...	No
46		.0020	.0508	24	.0057	...	No
47		.0020	.0508	36	.0051	...	No
48		.0020	.0508	48	.0041	...	No
7	B	.00025	.0064	72	.0230	4.2	Yes
18	1.78%N.	.00050	.0127	72	.0270	4.9	Yes
8	C	.00025	.0064	72	.0310	5.6	Yes
19	.84%N.	.00050	.0127	72	.0220	4.0	Yes
52		.00200	.0508	72	.0087	1.6	No
9	D	.00025	.0064	72	.0330	6.0	Yes
20	.44%N.	.00050	.0127	72	.0190	3.5	Yes
53		.00200	.0508	72	.0069	1.3	No
10	E	.00025	.0064	72	.0130	2.4	Yes
21	.41%N.	.00050	.0127	72	.0100	1.8	No
54		.00200	.0508	72	.0055	...	No
11	F	.00025	.0064	72	.0220	4.0	Yes
22	.46%N.	.00050	.0127	72	.0110	2.0	No
55		.00200	.0508	72	.0058	...	No
x	...	...	...	...	.0054	...	No

x—Sample of original material (Armco iron).

The analysis * for nitrogen of a layer 1 mm. thick cut from the subcoating surface of specimens selected from the copper plated group yielded the data of Table V.

The nitrogen content of specimens 45 to 48 inclusive, is apparently unaltered after carburization, thus indicating that a migration from the interior to the surface does not occur, nor is nitrogen introduced from the decomposition of occluded or entrained cyanide** within the matrix of the relatively thick coat of copper. The kaolin and fire-clay coatings did not con-

*Analyses made by Louis Jordan, chemist, Bureau of Standards.
**The use of a cyanide solution in plating the specimens suggested this as source of nitrogen contamination.

tain nitrogenous ingredients and contamination from these coatings would not be expected. The prevalence of nitride markings in all of the specimens covered with the enamel "ground coat" drew attention to the 3 per cent of sodium nitrate in the coating com-

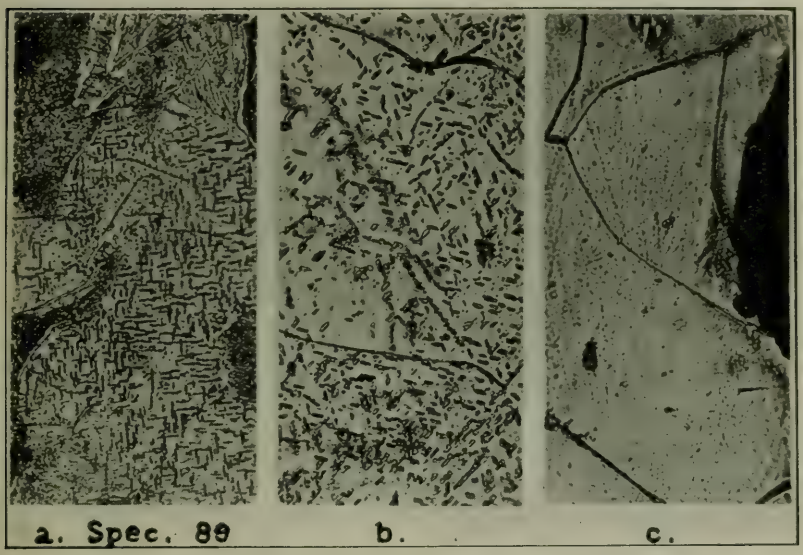

Fig. 8a—Nitrogen contamination traced to sodium-nitrate of ground coat. b. Small nitride needles appear in subsurface zone of specimen heated 1½ hours at 1000 degrees Cent. in ground coat plus charcoal mixture. c. Subsurface zone of specimen heated 1½ hours at 1000 degrees Cent. in "ground coat" mixture. x 500. Etched in 2 per cent HNO_3 in alcohol.

position. The source of the needles was attributed to the decomposition of the nitrate in the presence of carbon and iron at the carburizing temperature. Heating a specimen for 1 hour at 1000 degrees Cent. (1832 degrees Fahr.) in a crucible filled with a mixture of "ground coat" and charcoal in one instance and repeating the treatment on another specimen packed in the ground coat alone, yielded a perceptible nitrogen penetration in the former, which substantiated the explanation given above. Figs. 8-b and 8-c, illustrate the resulting structures. Replacing the nitrate with sodium carbonate should eliminate this effect.

The pronounced increase in the nitrogen content of thinly coated surfaces and the general increase in the nitrogen content of specimens exposed for progressively longer intervals of time

demonstrated that the gas was being introduced from a source extraneous to the specimens; obviously the carburizing gases. The nitrogen content of specimens 7 to 17 illustrates this point. The data of Table V show that no relation exists between the nitrogen content of the carburizers and the degree of contamination.

Summary

1. Experimental tests of carefully prepared, copper coatings were interpreted to yield empirical curves which show the progressive increase in the thickness of coating necessary to obtain protection against carburization for increasing periods of time. The curves are expressed in terms of carburizing time, plating time and plating thickness.

2. Experiments with mineral base coatings consisting of sodium silicate pastes with kaolin and fire-clay as the body materials, resulted in failure for the kaolin and a moderate success for the fire-clay mixture. Results obtained with 3 coats of an enamel "ground coat" mixture were equal or slightly superior to those of the much thicker coating of fire-clay. A pickled or roughened surface is necessary for the successful adherence of the "ground coat" and a similar surface would doubtless improve the adherence of other mineral-base mixtures.

3. A microscopic examination of exposed specimens frequently showed a concentration of carbon beneath the penetrable, copper-coated surfaces and evidence of an infiltration of nitrogenous compounds. The latter were found to originate from the carburizing gases, supplemented in one instance, by the decomposition of sodium nitrate in the "ground coat" mixture. Data are submitted in detail and structural features are carefully described.

In conclusion the authors wish to acknowledge the advice and assistance which Messrs. Blum, Thompson and Danielson so helpfully contributed toward the accomplishment of this work.

TESTING OF STEEL FOR HARDNESS

By H. M. German

DURING the discussion in the last symposium on hardness testing conducted by this society, the question was asked, "Would it not be possible to formulate some instructions as to how to use the different machines?" The machines under discussion were the Brinell, Rockwell and scleroscope. Acting upon the above suggestion, it was thought that a practical paper dealing with some of the most important factors and elements that introduce errors in the operation of these hardness-testing machines would be useful to the society. It is not difficult to operate the three machines in question, but when several operators testing a given piece of steel with the same machine at different times obtain widely divergent results, it is evident that there are factors in the machine and in its operation that introduce errors.

Brinell Hardness Testing

The Brinell test is a measure of hardness by deformation. In making a standard test a fixed pressure is applied on a hardened and polished steel ball 10 millimeters in diameter which in turn penetrates the test piece that is held in a rigid position. The diameter of the impression is proportional to the resistance of the piece tested. For iron, steel and the harder metals 3000 kilograms is the standard pressure, while for the softer metals like lead and babbitt metal, a moderated pressure is used. To obtain the hardness number corresponding to the diameter of the impression, the diameter of the impression may be read with a microscope having a graduated millimeter scale or the depth of impression taken by a micrometer attachment. The readings obtained may be referred to a chart which will transpose them to the corresponding degree of hardness or hardness number.

Several plants use the diameter of impression as the unit of hardness, as for example 3.2 instead of the hardness number 364. This term conveys the same meaning of hardness and saves time in computing or comparing with a chart to obtain the hardness

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A paper to be presented at the Symposium on Hardness Testing, annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, H. M. German, is metallurgist, Henry Disston & Sons, Philadelphia. Written discussion of this paper is invited.

number. The practice of reporting Brinell hardness should be standardized.

It is recognized that metals under mechanical work or compression when cold, change in hardness and become more resistant to deformation up to the point of rupture. The extent of this change of hardness varies not only in different metals but also according to the rate of application of pressure. Therefore, it must be understood that the Brinell test is a comparison and reliable results can be obtained only by testing like articles under like conditions.

The Brinell machine is still recognized as the leading standard for the engineer to compare different degrees of hardness on account of its accuracy and reliability when the necessary precautions are taken in making the tests. The Brinell machine has its limitations in that the standard test cannot be used for testing thin sections, those that will not stand a permanent deformation, or finished articles in which the depression mark would be objectionable. The standard pressure used for the test is 3000 kilograms and should be used whenever possible. However, by reducing the pressure the depth of depression will be decreased and thinner sections can be tested. If a series of test pieces having graduated degrees of hardness are prepared and readings taken with different pressures, it is not difficult to form a curve that will transpose readings at lower pressure to comparative readings at the standard pressure. A comparison curve for transposing readings at 1500 kilograms pressure to those at 3000 kilograms pressure is given in Fig. 1.

The gage limitation of specimens to be tested by the Brinell is also influenced by the hardness of the piece to be tested. For example, it is more possible to test a thinner section of high tempered steel than of low tempered steel as the impression will be much less in the former than in the latter. An impression which shows as a bulge on the opposite side will not give accurate results and should be discarded.

The minimum gage limits for Brinell and Rockwell tests on 1.00 per cent carbon steel hardened and tempered at different temperatures is shown in Table I. The results were obtained by hardening eight pieces of steel eight inches long by two inches wide by three-sixteenths of an inch thick, which had previously been ground

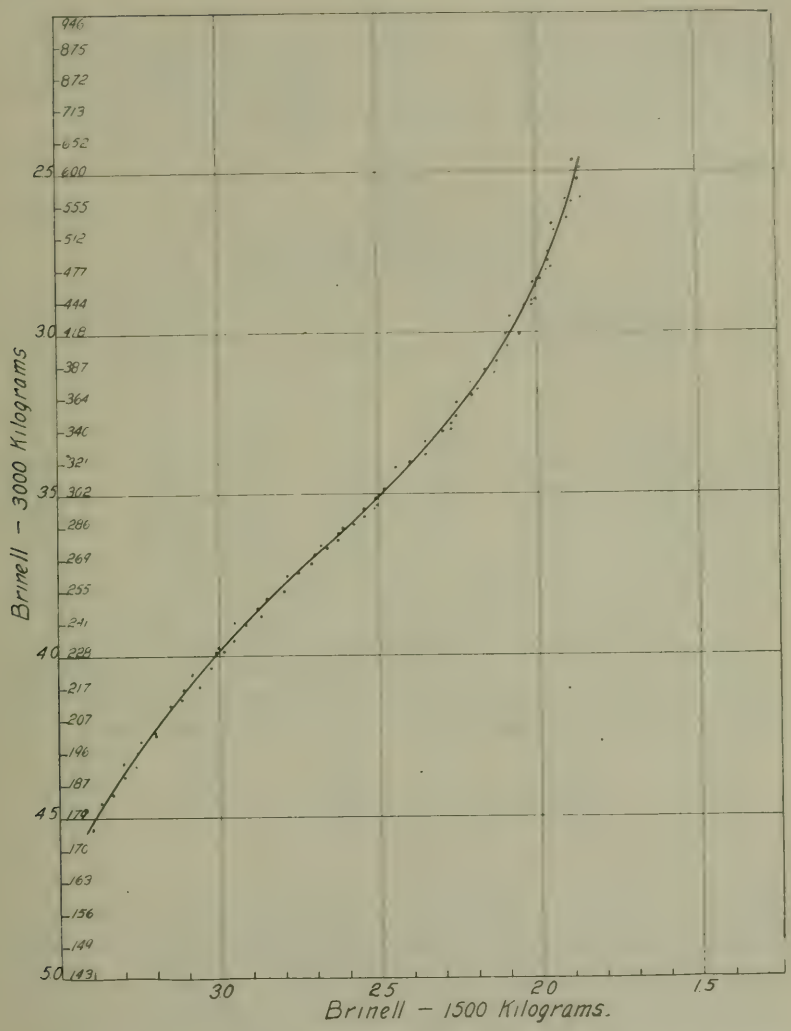

Fig. 1—Comparison Curve for Transposing Brinell Readings at 1500 Kilograms pressure to those at 3000 Kilograms Pressure Using a 10 mm. Ball.

to remove any presence of decarburization. The hardened pieces were then drawn at different degrees of heat and then taper ground and rough polished. A series of tests were then made on each piece at close intervals from the heaviest to the thinnest section and the point was noted at which the impression produced a bulge on

the opposite side and the readings were influenced. The thickness at this point was measured with a micrometer and was taken as the minimum gage limitation for that particular hardness. The method used in determining the limitation is illustrated in Fig. 2.

Table I
Minimum Gauge Limits for Brinell and Rockwell Tests at Different Tempers
1.00 Per Cent Carbon Steel

No.	Drawing Temp. Deg. Fahr.	Brinell Pressure 3000 Kg. Reading	Ga. Limit	Brinell Pressure 1500 Kg. Reading	Ga. Limit	Rockwell Steel Ball Reading	Ga. Limit
1.....	700	2.7	.050	2.2	.030	114	.023
2.....	800	2.9	.060	2.25	.035	113	.024
3.....	900	3.1	.065	2.4	.040	111	.026
4.....	1000	3.3	.070	2.5	.045	109	.027
5.....	1100	3.5	.080	2.6	.050	107	.029
6.....	1200	2.65	.090	2.8	.060	103	.031
7.....	1300	4.0	.105	3.0	.070	94	.034
8.....Anneal		4.4	.140	3.3	.085	87	.038

One of the greatest factors that will influence the Brinell results is the speed at which the pressure is applied. If the pressure is applied rapidly, the depression will be greater than if it is applied slowly and gradually. This error is strikingly shown when

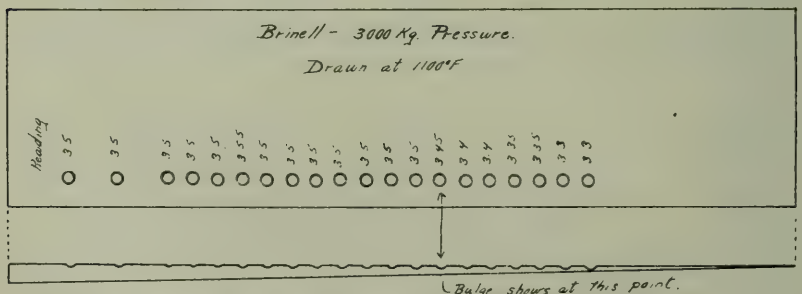

Fig. 2—Sketch of Test Piece Used to Determine Gauge Limitations.

comparing results obtained by an eccentric and weight type of machine with that using a hydraulic action. In the former the load is applied quicker and there is a greater swing of the weight than in the latter. Average readings on these pieces of annealed steel are as follows:

	No. 1	No. 2	No. 3
Lever Brinell—fast pressure	4.4 mm.	4.6 mm..	4.3 mm.
Lever Brinell—slow pressure	4.3 mm.	4.5 mm.	4.2 mm.
Hydraulic Brinell—normal pressure	4.15 mm.	4.4 mm.	4.15 mm.

Part of the above difference may be due to the type of machine used.

The average difference between a fast and a slow application of pressure with the hydraulic machine is about 0.1 millimeter in diameter for medium hard metals; the softer the metal, the greater will be the difference. A satisfactory period of time for applying the full load, is five seconds.

Another important factor that will influence the depth of indentation is the duration of time that the full pressure is applied in making the test. A short application of pressure will not give consistent readings as it requires time for the full pressure to exert itself in pressing the ball into the test piece and reach an equilibrium. This is clearly shown in the following test:

Period of Application Seconds	Brinell Readings				Average Reading
5	3.125	3.125	3.125	3.1	3.12
10	3.15	3.15	3.15	3.15	3.15
20	3.2	3.15	3.15	3.15	3.16
30	3.175	3.175	3.175	3.175	3.175
45	3.2	3.175	3.175	3.175	3.18
60	3.2	3.175	3.175	3.175	3.18

In this test the maximum reading was obtained at 45 seconds; there being no increase with an additional 15 seconds. In commercial testing the average duration is 10 seconds, but when more accurate readings are desirable, 30 seconds give consistent results. A standard time should always be used.

One weakness of the Brinell machine is that the steel balls frequently crack or become deformed. This source of trouble is naturally greater when testing harder pieces than when testing annealed pieces. A cracked or deformed ball may be detected when reading the indentation as it will be out of round. Oval shaped depressions should be discarded. There is at present considerable research work being done to obtain a nonbrittle, nondeforming ball and if successful, this source of error will be eliminated.

In order to obtain consistent readings, the following precautions should also be observed:

See that the surface of the test piece is at right angles to the direction of applied pressure and that it rests solid on the support.

See that the movable block on which the test piece rests is flat. The author has frequently seen blocks that had indentations made in them by the Brinell ball. This will give nonuniform results, particularly when testing thin sections. If the block is not flat, have it ground.

Check the reading glass frequently to see that the millimeter lines coincide with those of the standard. They occasionally get out of adjustment.

Check the instrument occasionally with a standard test block of known hardness. This should always be done when a new ball is used as they do not always seat properly in the plunger.

Rockwell Hardness Testing

The Rockwell test is a modification of the Brinell. It consists of pressing a hardened steel ball one-sixteenth of an inch in diameter or a diamond cone, of 120 degrees angle, into the piece to be tested and measuring the depth of depression with a dial micrometer. In order not to confuse readings, a separate scale is provided for the ball and diamond depression. The standard pressure applied for the maximum load is 150 kilograms when using the diamond cone and 100 kilograms when using the steel ball. The operating principle of the Rockwell machine is different from the Brinell in that the total depth of depression from the surface is not measured. In making a Rockwell test, a minor load of 10 kilograms, regulated by a spring, is first applied, the micrometer dial is set at zero, and then the major load is applied. Upon releasing the major load, the depth of depression caused by the major load only is indicated on the micrometer dial. This reading is taken as the degree of hardness. The Rockwell test has a special field in that it can be used for testing much thinner sections than the Brinell and it does not spoil the finish of the article tested, except on very highly polished work, but like the Brinell it has its limitation in that it cannot be used for testing thin sections

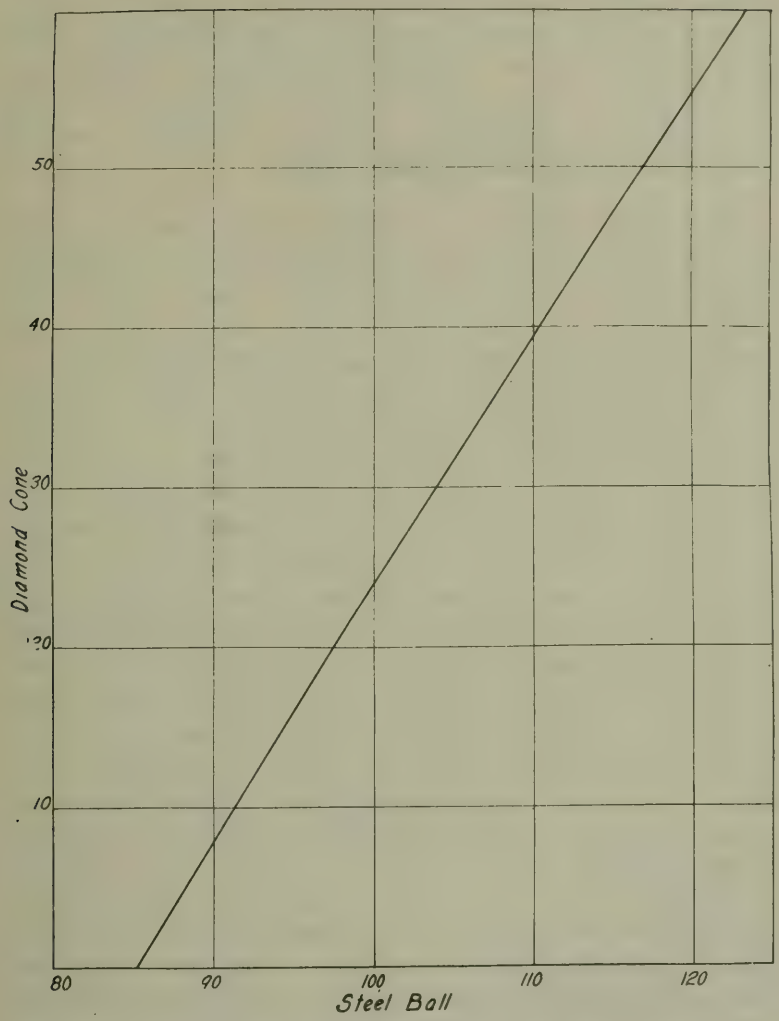

Fig. 3——Comparison of Steel Ball and Diamond Cone Rockwell Readings.

that are brittle or those that cannot stand a permanent deformation.

For testing very hard articles such as hardened high-speed steel, milling cutters, etc., the diamond cone has a very useful field as it will not deform and give inaccurate readings. Steel balls give much trouble in testing high tempered articles owing to their

tendency to break and deform under pressure and, if used, should be tested against a standard specimen at frequent intervals. When testing annealed and low tempered articles, the steel ball is preferred as it gives accurate results, it is less liable to break, and the scale has a wider range. Fig. 3 shows a comparison curve of steel ball and diamond cone Rockwell readings.

Since the Rockwell is an indentation test, the same factors that were discussed under Brinell testing, such as the rate of application of the major load and the length of time the load is applied, will influence the results. The rate of application can be varied by adjusting the strength of the major load spring. For accurate results, the time for applying the full load should not be less than five seconds, but if the test is made to roughly sort articles according to their hardness, the time may be lessened.

It must be clearly kept in mind that the Rockwell machine will test on a comparison basis. No factor or formula can be used that will convert hardness numbers obtained from one type of testing machine to that of another for articles of different compositions. If it is desired to convert Rockwell to Brinell or scleroscope terms, the best plan is to prepare a series of test pieces of the same gauge and finish that range from, hard to anneal, in temper, take readings with the different testing machines and plot a curve that will show a direct comparison of the readings. A comparison curve for straight carbon steel containing 1.00 per cent carbon, 7 gauge, is shown in Fig. 4.

Surface defects, such as scale or decarburized surface, do not affect the readings if they are not deep as the minor load overcomes their resistance, but if the thickness of scale or decarburized surface is excessive, the results will be misleading. If accurate readings of unknown samples are to be taken, it is a good plan to grind the surface before testing. Rockwell readings are not influenced by the smoothness or finish of the articles tested. You may confidently expect to obtain the same readings from polished articles that you get when testing them after they have been hardened and tempered. The results of a test made to show the influ-

ence of grinding and glazing on hardened and tempered pieces of 0.90 per cent carbon steel, 0.045 inches thick is as follows:

Readings were taken with a steel ball.

Sample Number	Hardened and Tempered	Rough Ground (Wet Sandstone)	Rough Glazed (No. 100 Emery)	Finish Glazed (Flour Emery)
1.....	116 —117	116 —117	116 —117	116 —117
2.....	116 —117	116 —117	116	116 —117
3.....	116	115 —116.5	115 —117	116 —117
4.....	115 —117	116.5—117	115 —117	117
5.....	116 —117	116 —117	116.5—117	117
6.....	115 —117	116 —117	116 —117	115.5—117

Special care should be taken in testing that the specimens are properly supported and horizontal. When the piece is large, the overhang should be supported in such a manner that it will not be raised or depressed when the major load is applied. Improper support of the pieces to be tested and the use of improper anvils are two of the greatest sources of errors in Rockwell testing.

After changing penetrators or anvils, readings should always be taken on a standard test piece until uniform and standard results are obtained, as the first few readings are unreliable. This is because it requires pressure for the penetrator, anvil and chuck to seat themselves properly.

Scleroscope Hardness Testing

The scleroscope, as invented by Shore, measures the height of rebound of a standard weight when allowed to fall from a given height upon the article to be tested. When a very hard substance, like a hardened steel ball or a diamond pointed hammer is allowed to fall on a horizontal surface, the height of rebound in proportional to the resilience of the article on which the hard substance falls. If the article to be tested is very hard, very little of the energy produced by falling weight will be dissipated by indentation and the energy will be almost entirely expended on the rebound. However, if the article to be tested is quite soft, considerable of the falling energy will be consumed in indentation.

The falling weight of the scleroscope is a steel cylinder one-fourth inch in diameter by three-fourths of an inch long. It has a diamond striking point about 0.020 of an inch in diameter, which

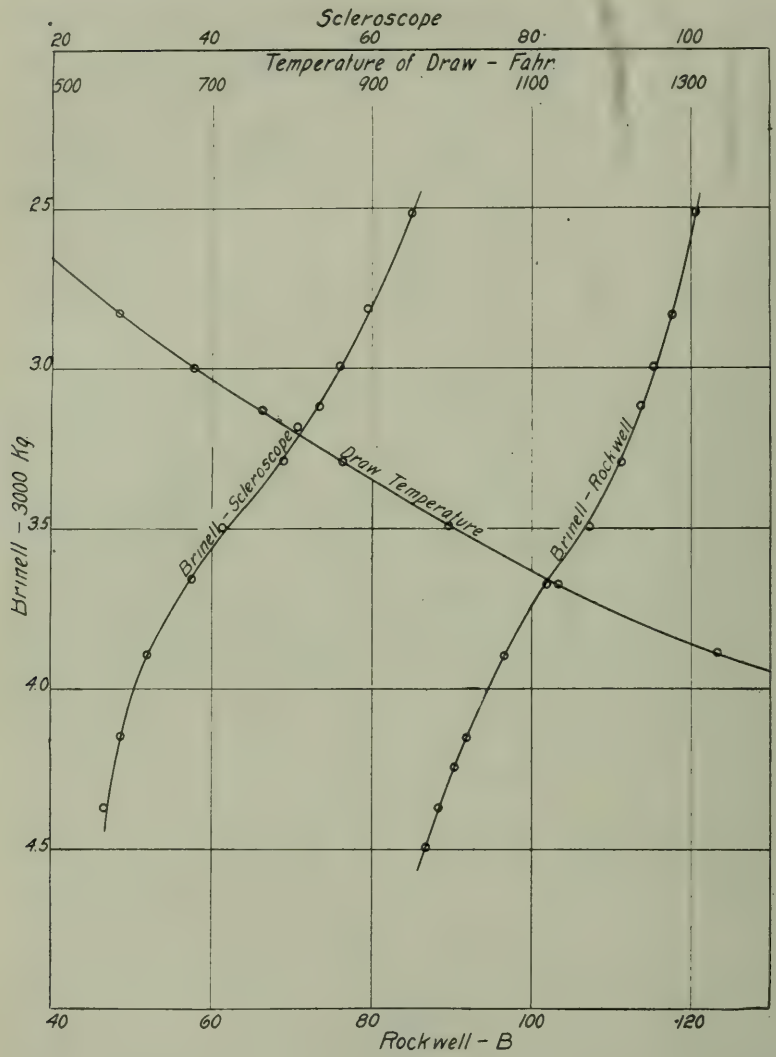

Fig. 4—Brinell, Rockwell and scleroscope Comparison Curves for a 1.00 Per Cent Carbon Steel.

is slightly spherical and blunt in shape. This weight is allowed to fall by gravity from a height of ten inches through a vertical glass tube on the article to be tested. The degree of hardness is measured by the highest point reached by the top of the weight on the rebound and is measured against a graduated scale in back of

the glass tube. The scleroscope does not spoil the finish of article to be tested, it can be used on very thin sections and by holding in the hand or supported on a movable arm is applicable for testing very large sections.

The scleroscope will give comparative results only when testing articles of like composition under like conditions. This point cannot be made too emphatic. By like conditions, we mean the same gauge or thickness and the same surface conditions as rough, ground or polished. If a comparison test is made between Rockwell and scleroscope readings on a number of thin and heavy test pieces all having the same Rockwell degree of hardness, the thin pieces will give a higher scleroscopic reading than the heavy pieces. This is illustrated by comparison curves Fig. 5, of Rockwell and scleroscope readings for different gauges.

The effect of different surface conditions on scleroscope readings may be shown by testing pieces of hardened steel after tempering and after receiving different degrees of grinding and polishing. The results of such a test on 0.90 per cent carbon steel, 0.045 gauge, are given in the following tabulation:

Sample Number	Hardened & Tempered	Rough Ground Coarse Wet Sandstone	Fine Ground Fine Wet Sandstone	Rough Polish No. 100 Emery	Fine Polish Polish Flour Emery
1.....	67—69	68—70	74—75	75—78	78—81
2.....	69—71	73—75	75—78	75—77	79—81
3.....	68—70	74—78	75—78	78—82	79—81
4.....	68—70	73—76	76—79	78—80	79—81
5.....	69—71	74—76	75—78	77—81	79—81
6.....	68—70	73—75	76—78	78—81	78—81

From the above results it is evident that it is impossible to compare the hardness of a rough ground piece with one having a highly polished surface and it emphasizes the fact that the scleroscope can only be used to compare like articles under like conditions.

Probably the greatest objection to the scleroscope is that the readings obtained from one instrument will not always check readings made by other machines on the same test piece. This has

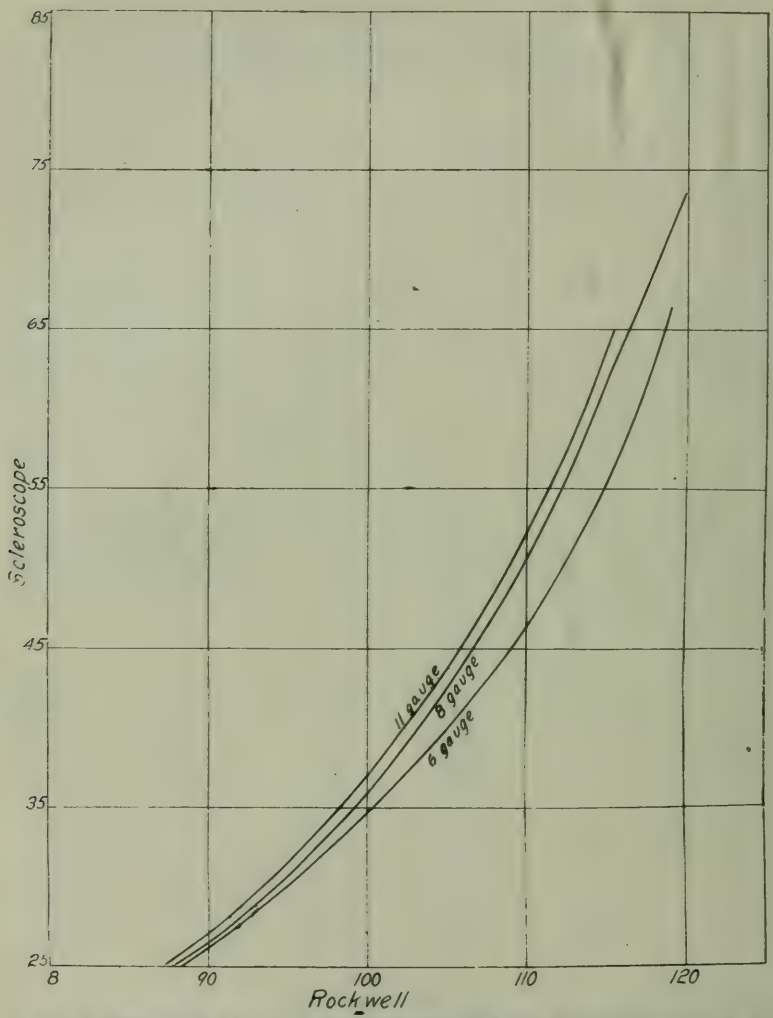

Fig. 5—Comparison Curves of Rockwell Steel Ball and Scleroscope Tests of Four Different Gauges of Metal.

been proven not only by checking readings of instruments that were in service for several months but also by checking new instruments and those returned to the manufacturers for repairs and recalibration. It frequently happens that two instruments will check on part of the scale but not throughout their entire lengths. When several instruments are in use, it is desirable to

select one for a plant standard and adjust all the others to agree with it. If an instrument is used to test a single class of work where the readings do not vary more than ten points, as for example 50 to 60, the instrument should be adjusted to check the standard in that range. The author has often felt that it would be quite an improvement in construction if the scale could be adjusted without removing the glass tube as adjustments could be easily and quickly made and the dangers of breaking and not reseating the tube properly would be eliminated.

As the hammer is permitted to fall freely, care should be exercised to keep friction between the hammer and the tube reduced to a minimum. This may be done by keeping the tube in a vertical position by means of the leveling screws and by frequently cleaning the inside of the tube and the hammer with chamois. When the scleroscope is used in a heat treating department or where the air is contaminated with smoke and oil fumes, the soot and oil adheres to the inside of the tube which causes friction and low readings. Also when the instrument is located in or near a chemical laboratory, the acid fumes will corrode the hammer. In replacing the top after cleaning, be sure that it is firmly seated in the proper position or the height of drop will be changed and the instrument will give wrong readings. In all cases, it is a good plan to keep the instrument covered when not in use.

The Brinell, Rockwell and scleroscope are all valuable hardness-testing machines, each having their own particular fields and limitations. The service which they will render depends upon the judgment and care of the operator in their operation and maintenance. It is hoped that this paper will prove an aid in securing consistent and interchangeable results and that it will supply an answer to the frequent question, "What is wrong with our hardness-testing machines?"

MAGNETIC INDICATIONS OF HARDNESS AND BRITTLENESS

By A. V. de Forest

HARDNESS tests owe their particular usefulness to the fact that they constitute the most generally known nondestructive method of judging the suitability of a metal. Furthermore they may be applied to any specimen with but little limitation from its size or shape, and are, therefore, applicable to finished products. In general, the other mechanical tests are limited to test pieces which are assumed to represent the actual material under study.

Particularly in heat treated steel, where the effect of shape and mass is relatively large, the logic of a vicarious test is frequently at fault.

Magnetic testing has frequently been proposed as a means of doing all this, and I shall here describe some recent developments along this line of investigation. The application of a form of this test as an inspection method has been described in a recent paper.[1] The use of this apparatus as an elaboration of the customary hardness test may properly be considered in this symposium on hardness testing.

It may seem superfluous to remark that testing of any kind should decide upon the suitability of the material for its intended purpose. Nearly always this means that it must have a certain proportion of mutually antagonistic qualities, such as strength and elongation, toughness and brittleness. The best relationship between these qualities is different for different compositions of steel, and frequently different for different heat treatments of the same steel. It can usually be determined only by a service test, or a laboratory test which simulates service conditions.

The customary procedure in selecting a steel and heat

(1) *Proceedings*, American Society for Testing Materials, 26th annual meeting, 1923.

A paper to be presented at the Symposium on Hardness Testing, annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, A. V. de Forest is research engineer, American Chain Co., Bridgeport, Conn. Written discussion of this paper is invited.

treating it for a particular purpose might be outlined in some detail in order to bring out the part played by a hardness test. Suppose for example we take a drill to be used on mild steel. To simplify matters we assume a fixed speed and feed. With any particular steel, for instance a simple 0.90 per cent carbon, we could quench from a suitable temperature above the critical range, draw to various temperatures and run cutting tests. From these we could select the best heat treatment and make hardness tests to correspond. A hardness figure would then represent a particular state of the steel, known to give suitable results but under the conditions of the test only. Under these conditions the hardness will be a function of the drawing temperature. If the character of the steel is changed or even the temperature of quench, or rate of cooling in the quenching bath, the hardness figure would be ambiguous, and perhaps misleading. It is within the experience of nearly all of us that two specimens of the same composition may be equally hard, yet one may be more brittle, in the sense of resisting impact, than other. A single magnetic reading can easily be made which will give a figure to be used in the same way as the hardness test in this instance.

An additional hardness test might be placed after the quench and before the draw. Here, if the temperature before quench and the rate of cooling be assumed constant, a figure can be made to indicate whether the character of the steel or the quenching operation is properly carried out. A combination of changes can, however, obscure a defect in either or both. Unfortunately in this case there can exist great differences in the brittleness of the quenched steel, with but little indication in the hardness.

One more step can be taken. The steel may be normalized, and the hardness measured. Here, some unsatisfactory stock could be eliminated, but again the hardness does not greatly depend on the factors in composition which make for or against a successful tool.

Suppose for a moment that a brittleness test were available. Something like a shock test only nondestructive and applicable to the material in its own shape instead of to a notched or prepared specimen. This test would depend upon other combinations of the qualities of the steel than those influencing the hardness.

With this and the hardness test at hand let us consider the same problem. Roughly speaking, this drill represents the possibility of trouble at four points. (1) In the composition or state of the steel before heat treatment, (2) in the temperature and time of the heat for quenching, (3) in the quench, (4) in the drawing operation. A test of the finished tool would show both the main factors necessary for a good tool; hardness with the greatest available toughness which heat treatment is capable of developing in that steel. The double test would show whether the tool were good, and if bad, perhaps to some extent why. It could not, however, show which of all four factors or combination of them was at fault. If the double test were applied after quench and before draw, we would know whether all were up to this point and if wrong there might be a characteristic indication in the hardness-brittleness ratio of where the trouble lies. A similar test on the raw material would indicate anything unusual in either factor, composition or physical state.

The magnetic method has not as yet developed such delightful possibilities as outlined above, but under suitable conditions can be used in the same way, and with similar results. It has the great advantage of speed. Feeding the material to the tester is the only limit, for the reading can be made as rapidly as a small mirror can swing a beam of light, and both "hardness" and "brittleness" tests can be carried out simultaneously. It fortunately happens that different magnetic properties of a steel are influenced in different proportions by different groups of physical properties. For this reason a reading can be made of a magnetic property which is mainly dependent on the same factors which determine hardness. This is a relatively simple measurement and can be easily carried out in numberless different ways. If, however, another group of magnetic qualities is measured in a suitable way, a reading can be made which depends very little on the hardness as affected by drawing temperature, but is greatly influenced by internal stress and grain size.

These are the very factors which are probably the most important in determining brittleness or its opposite, toughness. Moreover, one of these, namely internal stress, is exceedingly difficult to measure or even estimate by any test we have. Its influence on shock tests is certainly large; on fatigue tests it may in

theory have anything from an overpoweringly bad to a mildly beneficial effect. This magnetic measurement may then be treated in the same manner as our hypothetic brittleness test to use in conjunction with the mechanical test for hardness.

The effect of internal stress on shock and fatigue tests is illustrated in a rough way from the following experiments. Using a delicate recording dilatometer which could follow the volume changes in steel during quenching operations. Matsushita[2] showed that by rapidly cooling a 0.9 per cent carbon steel the austenite-martensite transformation could be depressed nearly to the temperature of the quenching medium. With the help of this instrument the steel could be withdrawn from the quench before the transformation had begun, but after it had been depressed below the temperature at which martensite is unstable. In this way the great change in volume from austenite to martensite responsible for most of the highly stressed conditions could be completed slowly in air instead of rapidly as is ordinarily the case in water quenching. In one case this transformation was delayed from the normal quenching rate of 20 seconds to 45 minutes with a slight difference in hardness in favor of the slow transformation. Any rate of cooling which depressed the transformation below 300 degrees Cent. yielded martensite of about the same hardness. Shock test, however, showed a very great difference in favor of this step method of quench, as Honda calls it. This merely provides figures to show the extent of the possible benefit which all good heat treaters know is derived from withdrawing any steel from the quenching bath before it is cold. The improvement is clearly to be ascribed to the lowering of internal stresses due to the delayed and gradual volume change.

The effect of internal stress on fatigue is somewhat more difficult to illustrate. It has, however, been observed by many experimenters that the fatigue limits of steel can be raised in some cases 20 per cent by slowly increasing the alternating load. This can most readily be explained on the basis of Jenkins[3] model as the improvement due to wiping out the internal stresses acting between different elements of the test specimen.

The magnetic relationships of all these varying properties have

(2) Matsushita, *Journal*, Iron and Steel Institute, May meeting, 1923.
(3) Jenkin, *Engineering* (London), Vol. 114, page 603, Nov. 17, 1922

not been fully explored. A few of the simpler ones were illustrated in the paper on my apparatus previously mentioned. There the magnetic effects of different elements of a heat treatment on several steels is shown. For instance in the case of high-speed steel the diagram of Fig. 1 was worked out. The "hardness" and "brittleness" magnetic measurements were plotted

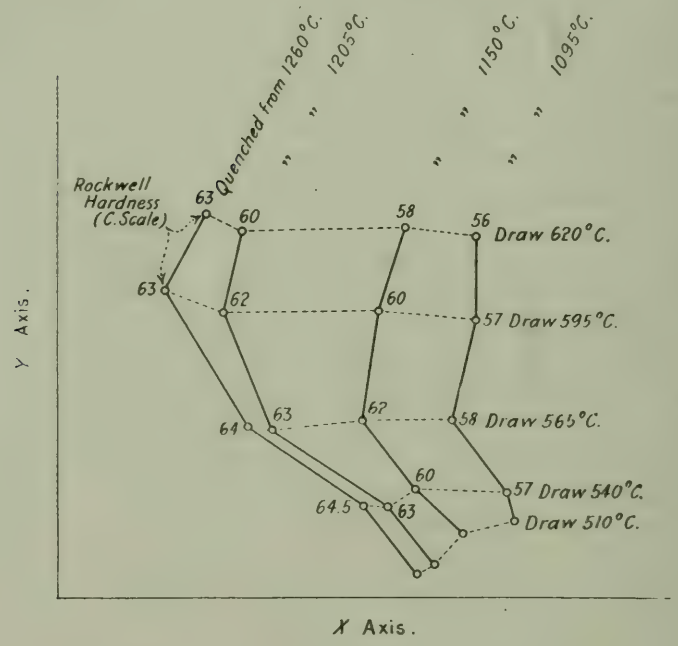

Fig. 1—Plot of Magnetic Data from 18 per cent Tungsten High-Speed Steel, Showing Effects of Quenching and Drawing. Specimens ⅜ x ⅜ x 3 inches.

respectively along two axes at right angles to each other and marked X-axis and Y-axis and these factors are expressed in terms of quenching and drawing temperatures. The full lines connect the readings of specimens having equal quenching temperatures, and the dotted lines connect those of equal draw. Figures on Rockwell hardness are also given and illustrate how impossible it is to determine two factors in terms of a single measurement. With the help of such a diagram to assist in the choice of a

particular heat treatment for a special purpose, the time spent in service tests can be greatly reduced.

One of the outstanding results of work so far is the great variation encountered in heat treated specimens even when made from the same bar of stock. If a group of ten pieces is hardened, say from 750 degrees Cent., another from 800 degrees Cent., instead of these forming two groups, they will almost invariably form nearly a continuous series from one minimum to one maximum specimen. From this series samples can be selected for test to show the differences to be regularly expected. Conversely, the differences between different specimens of the same stock and supposedly the same heat treatment give a logical measure for the improvement of the whole heat treating process.

Magnetic tests can be applied to the raw material from which tools are made and determine its suitability of structure and physical state. Bars unsuited for machining can be discarded or retreated. Tests on the finished product can prove the acceptability of the tool, and indicate what step is at fault in the heat treatment. As in the case of the analogous mechanical tests however, differences of size or material will produce results which cannot be interpreted without reference to service tests. This means that after the testing apparatus is at hand, a period of investigation is needed to interpret the findings into terms of service. This investigation is never complete but should always be in process of continuous growth toward the development of better results. I look forward to the help that such methods may give to the improvement of steel on the one hand and its heat treatment on the other.

THE HARDNESS OF "COMMON HIGH" SHEET BRASS

By Alvan L. Davis

BY THE above name is meant the usual rolled sheet brass of commerce, corresponding to an approximate composition of 66 per cent copper, 33½ per cent zinc, and ½ per cent lead, iron and other impurities combined. Such brass may be purchased in sheet form annealed to various degrees such as "light anneal," "drawing anneal," and "soft drawing anneal." It may also be obtained in various "tempers," which tempers are due to reductions in thickness by cold rolling, as indicated in the following schedule:

"Temper"	Reduction, B. & S. Gauge	Percent Reduction in Thickness
Quarter Hard	1—No.	11
Half Hard	2—No.	21
Hard	4—No.	37
Extra Hard	6—No.	50
Spring	8—No.	61

The object of this paper is to set forth briefly the average hardness, as determined by various methods, and also the range in hardness, to be expected in annealed and in hard-rolled sheet brass of the various tempers mentioned above. The data hereinafter presented has, in large part, been compiled from the published researches of: Price & Davidson[1], Mathewson & Phillipps[2], Phillipps & Gerner[3], C. H. Davis[4], Bassett & Davis[5].

Also certain unpublished work coming under the review of the author has been available.

1. Physical Tests on Common High Brass, American Institute of Metals, September, 1916.

2. Recrystallization of Cold Worked Alpha Brass on Annealing, *Transactions*, American Institute of Mining and Metallurgical Engineers, February, 1916.

3. *Chemical and Metallurgical Engineering*, June, 1919, page 622.

4. *Proceedings* of American Society for Testing Materials, 1917, page 164.

5. Comparison of Grain Size and Brinell Hardness of Brass, *Transactions*, American Institute of Mining and Metallurgical Engineers, page 428, Vol. LX, 1919.

A paper to be presented at the Symposium on Hardness Testing, annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, A. L. Davis, is metallurgist, Scovill Manufacturing Co., Waterbury, Conn. Written discussion of this paper is invited.

The hardness of brass is not developed in the same way as is generally the case with steel. The hardness of brass, of a given composition, is due to cold work, together with the greater or less degree to which such work has been relieved by annealing. In annealed brass its previous history as to annealings, and as to the stages and amounts of cold rolling, exerts a notable influence on the resulting hardness. In hard-rolled brass the hardening effect of

Table I

Variation in Hardness Tests, Made Upon a Single Homogeneous Sample

Type of Test	+ Variation in — Percent	Points
1. Erichsen cup test—depth of cup	12½	....
2. Shore test with universal hammer	5	1
3. Shore test with magnifier hammer	5	2
4. Rockwell test	4	3
5. Brinell test	3	3
6. Tensile test—ultimate strength	2½	1000 pound
7. Tensile test—elastic limit	2½	1000 pound
8. Erichsen test—pressure per m.m. depth of cup at point of rupture.	2½	....

rolling varies slightly according to the absolute thickness of the bar, as well as according to the manner of reduction—that is, whether a given percentage reduction is made in a single pass, or in several lighter passes. These differences appear in all the various hardness tests. Thus, brass of identical composition may show quite a range of hardness corresponding to a given temper, or corresponding to a specified anneal.

The reliability of any test depends upon the care taken in preparing the specimens, and in conducting the test. When all due care is taken there will still be a certain variation between successive tests on the same material, which is due to the machine used, and also to causes inherent in the test itself. This liability to variation may be expressed in form of a percentage of the mean of many tests. It may also be expressed in "points" on the arbitrary scale used for any given test. In Table I, the attempt is made to indicate approximately this variation, expressed in percentage, and in some cases in points on the individual scales of hardness. In cases where it is expressed in both forms it is to be un-

derstood that whichever is the greater, at any given point on the scale, is the variation to be expected.

If we now introduce a further source of variation, by testing different specimens, of various manufacture, but purporting to be all the same, the variations given above will be considerably increased, as will be seen in Table II.

Keeping in mind the above liability to variation, it is now proper to consider mean values of hardness corresponding to the

Table II

Variation in Hardness Tests, Made Upon Samples of Different Manufacture

Type of Test	+ Variation in — Percent	Points
1. Erichsen cup test—depth of cup	20	....
2. Shore test with universal hammer	12½	2
3. Shore test with magnifier hammer	12½	4
4. Rockwell test	11	6
5. Brinell test	9	6
6. Tensile test—ultimate strength	7½	3000 pounds per sq. in.
7. Tensile test—elastic limit	7½	2500 pounds per sq. in.
8. Erichsen test—pressure per m.m. depth of cup at point of rupture.	7½	....

Table III

Mean Hardness of Sheet Brass of Commerce

Condition	Per cent Reduction	Shore Univ.	Shore Mag.	Rockwell "B" Scale	Brinnell 500 K.G.	Ten. Ult. Str.	Tensile Elastic Limit	Pounds Pressure per mm. depth of cup
Annealed	0	10	19	20	54	46,000	11,000	314
¼ Hard	11	18	35	44	82	52,500	30,000	....
½ Hard	31	24	46	62	106	59,000	46,000	398
Hard	37	30	54	75	137	72,000	66,000	495
Ex. Hard	50	33	60	82	154	84,500	79,000	528
Spring	61	35	63	84½	162	92,000	88,000	....

different tempers of sheet brass. These mean values are set forth in Table III and shown in Fig. 1.

The following notes on various methods of testing are of interest:

Erichsen cup test.—The ordinary Erichsen cup test gives an indication of the drawing quality of metal of a given gage.

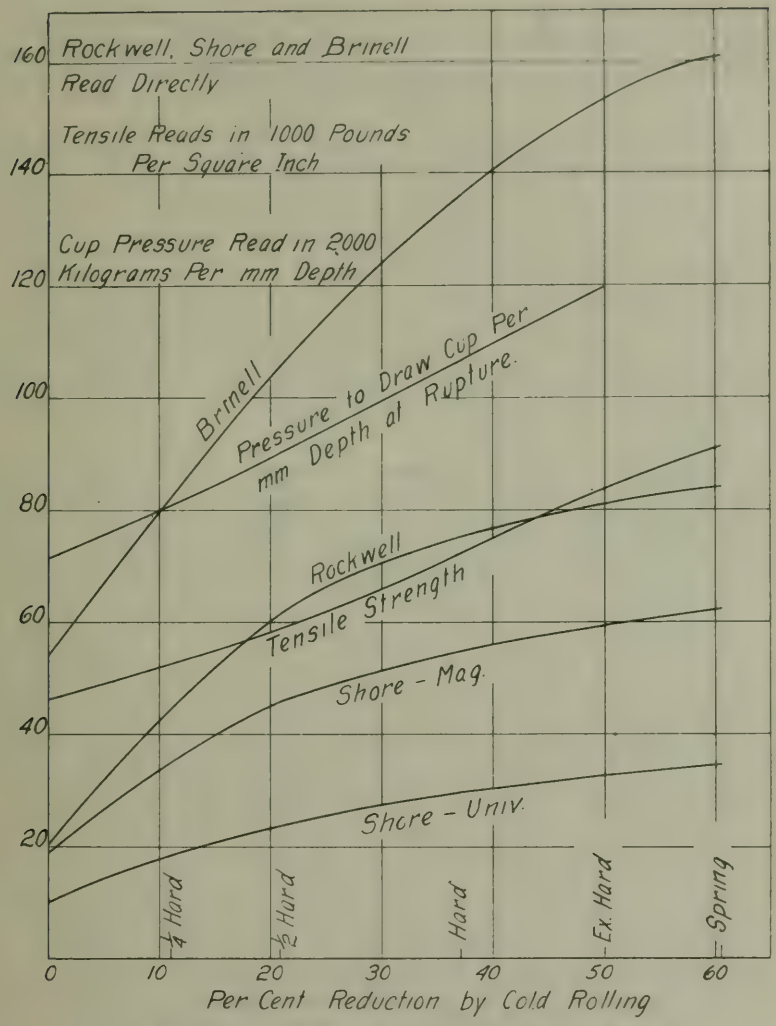

Fig. 1 Hardness Tests of Common High Sheet Brass

The thicker the sheet the deeper the cup. The only objection to the test is its liability to large variation. A modification of the Erichsen cup test is, however, of value. By measuring the pressure required to draw the cup, and expressing it as so much per mm. depth of cup, we get a seemingly accurate and sensitive measure of the work hardness of sheet brass; also, be it remarked, of sheet steel. Naturally the pressure varies with the gage of

the metal tested, but for a given gage the pressure per mm. depth of cup appears to be almost exactly proportional to the percentage reduction of the metal in cold rolling as will be seen from Fig. 1.

The Shore test is one very frequently used on account of its convenience and slight expense. It should be noted that results upon metal less than 0.020 inches gage are not consistent with those obtained on thicker gages. Such results run low, especially for "quarter hard" and "hard" tempers.

The Rockwell test is convenient and has much to recommend its use. It is available on metal considerably thinner than may properly be tested under the Brinell machine. However, it can not be used on exceedingly soft metals where the Brinell machine can be used.

The Brinell test, for specimens sufficiently thick, is probably more reliable than either the Shore or Rockwell, but the results are not comparative when used on brass thinner than 0.064 inches annealed, and 0.051 inches hard rolled, when 500 kilograms pressure is applied to a 10 mm. ball.

The tensile test gives a very reliable measure of the degree of anneal, or of the amount of cold work to which sheet brass has been subjected. The main objection to the tensile test is the time and expense required for its application. It should be noted that the yield point cannot be obtained by the drop of the beam method, which is frequently used in testing steel.

EFFECT OF HEAT TREATMENT ON LATHE TOOL PERFORMANCE AND SOME OTHER PROPERTIES OF HIGH-SPEED STEELS

By H. J. French, Jerome Strauss and T. G. Digges

Prefatory Abstract

This report is concerned with the time-temperature relation in the hardening and tempering of high-speed steels and their effects upon lathe tool performance, constitution and dimensional changes. Comparisons of endurance are also given at various cutting speeds of the four most important of the current steel types for roughing tools and the relative advantages and disadvantages of each are discussed. In addition the "Taylor" and "Breakdown" tests for lathe tools are compared and some of the limitations of the former are described in detail. Finally the prevention and elimination of so-called "flaky fractures" in the heat treatment of high-speed steels has been considered.

The principal conclusions drawn from these tests may be summarized as follows:

(1) *The endurance of high-speed steels is affected to a marked degree by the high-heat temperature used in hardening and rises rapidly with increase above* 2200 *degrees Fahr. However, a point is finally reached where a further temperature rise is no longer attended by a commensurate increase in the endurance and if high enough heats are employed, a decrease will be observed coincident with a partial melting of the steel. Under otherwise fixed conditions there is therefore a high-heat temperature which results in maximum endurance but this varies with composition. It is higher in the* 18 *per cent tungsten than in the* 13 *per cent tungsten steels and is raised in both types by the addition of* 3 *to* 5 *per cent cobalt.*

(2) *The best hardening temperatures for the four*

*Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

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main types of high-speed steel, to be used as lathe tools under severe service, are considered to be about as follows:

2350 *degrees Fahr. for low tungsten-high vanadium steel*

2400 *degrees Fahr. for high tungsten-low vanadium and low tungsten-cobalt steels.*

2450 *degrees Fahr. for high tungsten-cobalt steel.*

These temperatures are a compromise between several factors including tool endurance and brittleness.

(3) *The endurance of high-speed steels is likewise dependent upon and within limits, increases with the time at high heat. In tests made with high tungsten-low-vanadium steel, tools held 3 minutes at 2280 degrees Fahr. had superior endurance to those held 30 seconds at 2400 degrees Fahr. but were not as good as those subjected to the latter temperature for 1½ minutes. Therefore, for consistent results both time and temperature should be controlled by suitable instruments.*

(4) *High-speed steels subjected to the severe service described were found to have endurance characteristic of the high temperature treatment used in hardening and this was not modified to any great degree by any subsequent tempering up to and including 1100 degrees Fahr. However, the higher the tempering temperatures the tougher did the steel become. Thus the most important reason for tempering, in this case, is not increased endurance but decrease in brittleness.*

(5) *Length shrinkage or expansion may be produced in hardening a high-speed steel from a given temperature, if this is not too high, by varying the treatment prior to hardening. This includes both preliminary annealing and the manner of heating for hardening. However, the higher the quenching temperature and the time at high heat, within limits ordinarily encountered in commercial heat treatment, the greater will be the expansion or, under certain conditions, the less will be the shrinkage. Likewise tempering subsequent to hardening may be used to reduce original length shrinkage or expansion but the final length will approximate the original only in certain cases. The tempering which will produce this ideal condition will vary widely in a given steel depending upon the previous history of the samples but in no case is it possible to completely compensate for hardening changes in two dimensions.*

(6) *In a series of tests on nickel steel forgings in*

which the cutting speed was varied from about 45 to 70 feet per minute, high-speed steels containing about 3.5 per cent cobalt had much greater endurance than the plain chromium-tungsten-vanadium steels. Under the most severe service the low tungsten-cobalt type was superior to the high tungsten-cobalt steel but at the lowest speeds both had comparable endurance. Comparisons of the four steels tested when based on the breakdown test, showed the following average order of superiority:

	Per Cent
Low tungsten-cobalt steel	98
High tungsten-cobalt steel	90
Low tungsten-high vanadium steel	68
High tungsten-low vanadium steel	47

(7) *Low tungsten steels, with or without cobalt additions, are more sensitive to heat treatment than the high tungsten types. They are more brittle when hardened for maximum endurance but require lower hardening temperatures than do the corresponding high tungsten steels. These features, in addition to comparisons of endurance, must be considered in selecting steels for particular service. No one type of high-speed steel meets all requirements but each has its advantages and disadvantages.*

(8) *Both the "Breakdown" and "Taylor" tests have limitations and cannot wholly replace the method of using tools in the shop to determine just what they will do. However, much worthwhile information of practical value can be obtained in relatively short time by careful interpretation and correct application of results obtained by either test.*

(9) *In normal shop practice so-called "flaky" steel may be produced through the hardening of long lengths of lathe, planer and shaper tools followed by dressing operations in which only part of the previously hardened steel is heated to annealing temperatures which would ordinarily prevent its occurrence. As "flaked" steel is brittle and showed a tendency toward erratic results in lathe tests, its production is to be avoided.*

(10) *Prevention of "flaky" fractures in ordinary high-speed steel in heat treatment is much more simple than elimination and may be accomplished by annealing between successive hardening treatments. In no case when once produced, was complete elimination effected by annealing alone though certain complicated treatments left mere traces of this structure upon rehardening.*

However, combined forging and annealing completely removed severe "flake" in all steels tested. In general the greater the reduction in forging the lower was the annealing temperature required for a cure (within limits).

(11) *High tungsten-low vanadium steels offered the greatest resistance to the formation of "flake" and likewise to its elimination when once produced.*

I Introduction

In a previous report[1] concerned with some limitations of the competitive "lathe breakdown test" and the endurance of various modern high-speed steels, attention was called to the wide variations in heat treatment recommended by different manufacturers for steels of the same type intended for specific service. For example, high heat temperatures from 2300 to 2500 degrees Fahr. and subsequent tempering from 450 to 1100 degrees Fahr. were suggested and used by various producers for high tungsten-low vanadium steels in two series of competitive tests. Likewise in the case of high tungsten steels containing colbalt one manufacturer used a very high heat for a short time while another preferred a somewhat lower temperature for a longer time.

Comparison of recommended treatments contained in tool steel catalogs of many producers shows as great if not a greater variation and a search of the technical literature reveals many opinions regarding the proper time-temperature relations for use in heat treatment but few experimental data from which detailed comparisons can be made.

The present tests supplement those already described[2] and were made to furnish information concerning the effects of such variables as high heat temperatures, time at high heat, manner of preheating and tempering temperature upon the endurance of the four most important types of high-speed steel, namely, (a) low tungsten-high vanadium, (b) high tungsten-low vanadium, (c) low tungsten-cobalt and (d) high tungsten-cobalt steels. In addition a study was made of the effects of some of these variables upon dimensional changes in hardening to throw further light upon the dis-

(1) H. J. French and Jerome Strauss: "Lathe Breakdown Tests of Some Modern High-Speed Tool Steels," *Transactions*, American Society for Steel Treating, Vol. 2, No. 12 (September, 1922), page 1125; Bureau of Standards *Technical Paper* 228.

(2) Refer to (1).

agreement in results recently reported by Grossmann and Spaulding[3].

There was also carried out a limited study of the prevention and elimination of "flaky" fractures in order to complete what may be characterized as a general investigation of the heat treatment of high-speed lathe tools.

II Materials and Methods Used

The chemical compositions of the several steels used in the tests to be described together with preliminary annealing treatments are shown in Table I. In the heat treatment of these steels the time-temperature relations in all operations were carefully controlled and special precautions taken to obtain uniformity. This applies not only to the high heats and subsequent tempering but to preheating as well. Gas fired semimuffle furnaces were used in all cases except for tempering and for this operation oil baths or electrically heated muffles were employed. All temperatures were measured by platinum thermocouples and potentiometers and stop watches were used to control time at the high heat.

In general, preheating was carried out by first warming the tools and then introducing them into a furnace held at 200 degrees Fahr. below the desired temperature. The furnace temperature was then slowly raised and upon reaching that desired was held constant for 20 minutes. In preheating samples for dimensional change determinations the steel was placed in a cold furnace which was then heated at less than 18 degrees Fahr. per minute to the specified preheating temperature.

All tools had a cross section of ¼ x ½ inch and were made from bars finished to this size in the mills. They were ground to front and side clearances of 6 degrees, side slope of 14 degrees, back slope of 8 degrees and had a nose radius of 1/8 inch. These angles are identical with those of the small tools used in previous tests and the same precautions were observed in carrying out the experiments as have already been described[4].

The cutting angle (tool to surface of the log) was 90 degrees and the tool nose was set at dead center. Except as otherwise

(3) M. A. Grossmann: "The Change in Dimensions of High-Speed Steels in Heat Treatment, *Transactions*, American Society for Steel Treating, Vol. 2, No. 8 (May, 1922), page 691; discussion of the above paper, Vol. 2, No. 10 (July, 1922), page 890.

(4) Refer to (1).

Table I

Chemical Compositions of the High-Speed Steels Tested and Preliminary Annealing Treatments Used.

Steel No.	Type of Steel	Chemical composition, per cent										Annealing treatment used
		C	Cr	W	V	Co	Mn	P	S	Si	Ni	
	Steels used in lathe tests											
A	Low tungsten-cobalt	0.65	4.00	13.92	1.49	3.63	0.44	0.013	0.019	0.17	0.06	1600°F—3 hours—furnace cool
B	High tungsten-cobalt	0.68	3.67	17.97	0.73	3.06	0.42	0.013	0.016	0.15	0.04	1600°F—3 hours—furnace cool
C	Low tungsten-high vanadium	0.68	4.37	13.91	1.64	0.09	0.42	0.022	0.013	0.16	0.12	1600°F—2 hours—furnace cool
D	High tungsten-low vanadium	0.64	3.93	18.33	0.85	None	0.39	0.017	0.017	0.06	None	1600°F—3 hours—furnace cool
	Steels used in transverse tests and for observations on dimensional changes, etc.											
Z	Low tungsten-high vanadium	0.74	4.05	12.58	1.67	None	0.27	0.029	0.018	0.09	Trace	1600°F—2 hours—furnace cool
CC	High tungsten-cobalt	0.68	3.47	18.46	1.01	3.48	0.11	0.014	0.015	0.05	None	1600°F—2 hours—furnace cool
H	High tungsten-low vanadium	0.62	3.92	17.67	0.70	None	0.28	0.015	0.020	0.12	Trace	1600°F—2 hours—furnace cool
A 34	"Die steel"	0.56	2.21	13.80	0.98	...	0.42	...	...	...	0.20	Tested after various preliminary treatments as shown in subsequent tables.

Table II

Chemical and Physical Properties of the Test Logs Used.

Log No.	Chemical composition -- per cent C	Mn	P	S	Si	Ni	Cu	Tensile tests made at diameters shown in inches(a)	Tests at 90 degrees to the log axis. Proportional Limit 1000 lb. per sq. in.	Tensile Strength 1000 lb. per sq. in.	Elongation in 2 inches Per Cent	Reduction of Area Per Cent	Tests parallel to the log axis Proportional Limit 1000 lb. per sq. in.	Tensile Strength 1000 lb. per sq. in.	Elongation in 2 inches Per Cent	Reduction of Area Per Cent
1 & 2	0.29	0.83	0.042	0.047	0.27	3.51	0.10	10.0	60.9	100.4	20.0	24.4	55.8	100.9	23.3	41.4
								5.5	55.2	101.7	14.5	17.2	60.3	102.5	24.3	40.8
3	0.37	0.77	0.043	0.029	0.35	2.97	0.22	8.9	60.8	102.7	21.3	36.0	58.8	103.3	27.0	57.5
								4.5	56.8	99.0	17.3	22.6	57.8	100.3	26.0	53.8
4	0.35	0.69	0.024	0.028	0.37	3.09	0.34	9.7	60.2	98.1	16.0	28.0	64.2	99.8	26.0	59.8
								2.6	53.0	95.8	14.3	20.8	53.0	95.5	25.5	55.1
5	0.25	0.79	0.034	0.011	0.32	3.58	0.40	8.0	62.1	95.5	15.0	22.2	55.2	96.1	27.0	54.7
								3.3	59.9	94.7	16.3	22.6	52.7	96.2	25.5	48.8
6	0.25	0.76	0.025	0.034	0.32	2.87	0.37	9.3	67.2	98.0	16.7	28.1	67.2	98.8	23.7	56.7
								2.9	62.1	96.7	14.0	20.8	60.3	97.7	23.0	48.8
7	0.37	0.82	0.026	0.042	0.22	3.42	0.28	8.9	72.3	102.8	15.2	24.0	72.3	102.8	22.0	48.0
								4.4	68.2	97.5	10.0	17.0	72.9	99.3	19.7	40.0
9	0.33	0.68	0.041	0.037	0.27	3.24	0.30	9.5	65.2	96.7	15.5	23.5	65.2	97.3	25.0	52.2
								3.9	64.2	97.3	15.7	23.6	60.1	95.2	23.0	50.0
10	0.36	0.89	0.030	0.041	0.24	3.63	0.28	8.7	49.0	118.2	10.5	19.6	49.9	117.1	17.0	22.9
								4.5	46.8	114.0	12.5	18.2	45.1	117.5	15.5	18.7
11	0.34	0.77	0.031	0.040	0.31	3.60	0.22	10.2	63.0	99.8	15.0	21.8	69.3	99.8	23.5	51.5
								5.2	67.2	97.5	19.0	30.8	66.9	98.4	24.0	48.9
12	0.29	0.85	0.032	0.040	0.26	2.58	0.36	9.4	69.2	102.8			71.4	103.4	23.0	56.0
								4.3	68.2	98.8	17.0	27.0	68.2	98.0	22.0	46.0
13	0.26	0.95	0.035	0.022	0.45	3.57	0.41	8.3	62.8	123.7	15.2	24.5	68.2	121.7	20.7	42.0
								4.9	62.1	119.1	15.5	26.3	62.1	123.5	16.8	38.6
14	0.38	0.94	0.039	0.029	0.31	3.48	0.41	9.3	68.0	127.3	12.8	22.1	64.1	128.3	13.5	26.0
								7.0	56.0	125.8	10.0	12.8	60.1	125.2	10.0	15.4
15	0.26	0.95	0.035	0.022	0.45	3.57	0.41	7.8	64.1	123.2	13.9	17.8	66.2	124.2	19.0	35.7
								5.6	62.1	121.2	12.8	17.8	64.1	121.9	14.0	29.7
16	0.26	0.65	0.033	0.028	0.30	2.77	0.26	9.6	55.2	96.2	15.3	37.8	57.0	98.5	22.3	53.6
								7.7	55.2	93.9	12.0	18.7	52.9	92.1	21.8	47.6

(a) These figures represent starting and finishing diameters in the lathe tests and show degree of uniformity of the logs.

indicated the tools were run dry at 70 feet per minute, calculated at the bottom of cut, with a feed of 0.028 inch and a depth of cut of 3/16 inch. The chemical and physical properties of the test logs used in each series of tests are shown in Table II.

III Experimental Results

1. *Variation in High Heat Temperature Versus Tool Endurance*

The effects of varying high heat temperature on the endurance of the four high-speed steels subjected to severe service

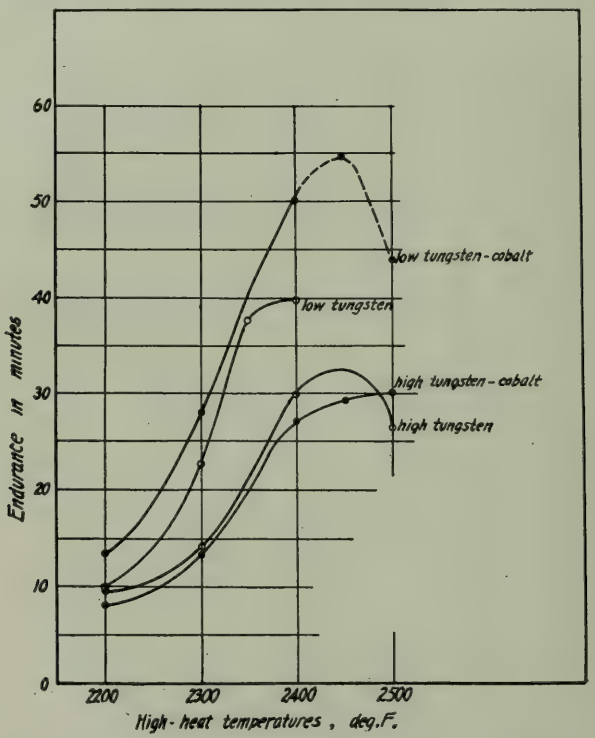


Fig. 1—Effect of high heat temperature on the endurance of four high-speed steels. Steel compositions are given in Table I and the properties of the test logs in Table II. The peak of the curve for low tungsten-cobalt steel is dotted as many of the tools quenched from above 2400 degrees Fahr. were still cutting well and showed no signs of failure at the end of 60 minutes, at which all tests were stopped. The form of the curve is considered correct but the actual endurance values are approximate.

in cutting nickel steel forgings are shown in Table III and reproduced graphically in Fig. 1. Attention is called to the fact that the various steels were tested on four different sets of test logs

Table III

Lathe Tool Endurance of 4 Types of High-Speed Steel Subjected to Various High-Heat Temperatures in Hardening.

Steel No.	Type of Steel	Heat treatment (a) High Heat Temp. in degrees Fahr.	Heat treatment (a) High Heat Time in minutes	Endurance in Minutes — 1st grind: On log. No.	1	2	3	4	2nd grind: On log. No.	1	2	3	4	3rd grind: On log. No.	1	2	3	4	Average all tests
C	Low tungsten....	2200	2	1	8.4	7.4	6.0	13.4	3	4.4	17.5	7.4	2.5	4	11.2	18.6	13.2	9.9	10.0
		2300	2	1	18.6	25.7	22.7	22.7	3	19.3	13.4	12.8	14.6	4	32.2	43.2	24.8	21.3	22.6
		2350	2	1	....	28.4	28.4	26.2	3	38.8	40.9	....	34.4	4	50.2	....	....	53.1	37.6
		2400	2	1	32.9	39.6	40.4	30.2	3	....	....	....	....	4	44.0	40.7	32.8	56.6	39.6
D	High tungsten...	2200	1½	9	7.6	8.2	15.0	5.8	9	10.9	11.0	7.1	10.8	....	....	....	....	....	9.6
		2300	1½	9	10.9	....	9.4	17.4	9	15.6	....	21.5	12.0	9	12.7	....	12.8	....	14.0
		2400	1½	9	25.2	26.3	28.7	24.1	9	28.7	36.6	39.0	30.6	....	....	....	....	....	29.9
		2500	1½	9	26.8	20.0	....	28.1	9	26.4	29.5	27.7	26.4	....	....	....	....	....	26.4
A	Low tungsten-cobalt.....	2200	1½	2	16.6	18.2	6.0	17.1	3 & 4	....	24.9	16.2	21.2	....	....	....	....	....	....
		2200	1½	6	11.0	8.2	11.1	8.2	6	14.8	....	9.5	7.5	....	....	....	....	....	13.6
		2300	1½	2	20.8	23.2	14.8	....	3 & 4	31.6	29.6	30.3	....	....	....	....	....	....	
		2300	1½	6	28.5	30.4	28.7	39.5	6	24.3	25.4	....	....	....	....	....	....	....	28.1
		2400	1½	2	24.1	33.2	49.5	39.4	3 & 4	39.5	68.3	60.8	B	....	....	....	....	....	
		2400	1½	6	(60)	B	59.3	(60)	6	(60)	(60)	37.2	....	....	....	....	....	....	50.1
		2450	1½	6	B	B	45.3	53.5	6	B	B	(60)	(60)	....	....	....	....	....	54.7
		2500	1½	2	B	46.5	B	41.3	3 & 4	B	B	B	B	....	....	....	....	....	43.9
B	High tungsten-cobalt.....	2200	1½	7	3.6	6.8	8.8	8.7	7	9.3	8.0	11.5	7.5	....	....	....	....	....	8.0
		2300	1½	7	8.5	15.0	17.4	12.0	7	15.1	15.0	10.9	12.1	....	....	....	....	....	13.3
		2400	1½	7	23.9	28.5	21.6	26.5	7	24.9	34.2	28.9	27.8	....	....	....	....	....	27.0
		2450	1½	7	25.9	40.4	26.6	....	7	22.1	29.9	....	....	....	....	....	....	....	29.0
		2500	1½	7	40.0	26.6	33.6	22.8	7	41.1	24.6	29.4	22.8	....	....	....	....	....	30.1

Note regarding figures in brackets: These tests were stopped at the times indicated as the tools were still cutting well and showed no signs of failure.

(a) All tools preheated for 20 min. at 1600 degrees Fahr.; quenched from the high heat in No 2 soluble quenching oil (E. F. Houghton Co.) tempered after hardening at 1090 to 1100 degrees Fahr., for 30 min.

B—Tool broke.

and even though these have comparable tensile properties no direct comparisons of cutting time are justified. The tests were made to show the relation of performance to high heat temperature in each steel and a number of important features are revealed.

A given rise in quenching temperature above 2200 degrees Fahr. produces a greater increase in endurance in low tungsten steels, with or without cobalt additions, than in the high tungsten types. In other words the slope of the high heat temperature-endurance curves is not as high for the latter types as for the former. As already reported[5] greater variations in Brinell and Shore hardness are also encountered in the low tungsten steels under varying thermal treatments so that it is safe to say that these are more sensitive to heat treatment than steels containing high (18 per cent) tungsten.

The general form of the curves shown in Fig. 1 is the same for all steels and shows a very marked increase in endurance as the high heat temperatures are raised. However, a point is finally reached where a further temperature rise is no longer attended by a commensurate increase in the endurance and if high enough heats are employed a decrease will be observed coincident with a partial melting of the steel.

Under otherwise fixed conditions there is therefore a high heat temperature which results in maximum endurance, but this varies with composition. It is higher in the 18 per cent tungsten than in the 13 per cent tungsten steels and is raised in both types by the addition of cobalt.

Thus for maximum endurance extremely high temperatures in the neighborhood of 2500 degrees Fahr. are required for the high tungsten-cobalt steel, intermediate temperatures around 2450 degrees Fahr. for the low tungsten-cobalt and high tungsten-low vanadium steels and the lowest temperature around 2400 degrees Fahr. for the low tungsten-high vanadium steel.

These temperatures are not recommended, however, for the time factor is of great importance and there is danger of passing the "peak" of the curves shown in Fig. 1 by "over-exposure" at the high heat. In addition, the steels, and particularly those containing 13 per cent tungsten, show a greater degree of brittleness than is desirable even in a lathe tool where adequate support can

(5) Refer to (1).

be given. The best hardening temperature is therefore a compromise between the several factors mentioned and is considered to be about as follows for lathe tools treated and used under conditions similar to those of the present tests:

For low tungsten-high vanadium steel about 2350 degrees Fahr.
For high tungsten-low vanadium steels about 2400 degrees Fahr.
For low tungsten-cobalt steels about 2400 degrees Fahr.
For high tungsten-cobalt steel about 2450 degrees Fahr.

While these tests show the extreme importance of high heat temperatures in hardening for development of maximum tool endurance they likewise have a direct bearing upon selection of steels under given conditions of service. For example, the somewhat greater sensitivity to heat treatment of the low tungsten steels and the fact that they are more brittle than those containing 18 per cent tungsten means greater variations in performance in shops where inadequate heat treatment facilities are afforded or insufficient care taken in handling tools and possibly also greater tool breakage, though brittleness is generally of minimum importance in lathe roughing tools.

The higher the temperatures required in hardening the greater will be the oxidation and scaling of the tools and deterioration of furnace equipment. Thus the very high heats required in the high tungsten-cobalt steel must have compensation in greater average tool endurance or some other feature for selection in competition with the other types. These features are merely mentioned at this time to indicate the possible application of the data described. A more complete discussion of these questions will be given in subsequent sections of this report.

2. *Effect of Tempering on Tool Performance*

The effects of various tempering temperatures subsequent to hardening upon the endurance of the four high-speed steels are shown in Table IV and Fig. 2. The best high heat temperatures, as previously determined, were used in each case but an additional set of tests was carried out on the low tungsten-high vanadium steel after hardening from a low temperature (2200 degrees Fahr.) as this procedure when combined with a low temperature drawback is recommended by a prominent manufacturer. Quenching directly into lead was also tried as the properties developed by such treat-

ment have often been discussed but the tools were so brittle that no satisfactory endurance tests could be made.

Variation in tempering temperature has only a minor effect upon tool endurance under the described conditions of test though there is observed a slight increase in cutting time when tempering between 600 and 1100 degrees Fahr. This effect is most marked in the high tungsten-cobalt steel but is also shown in the

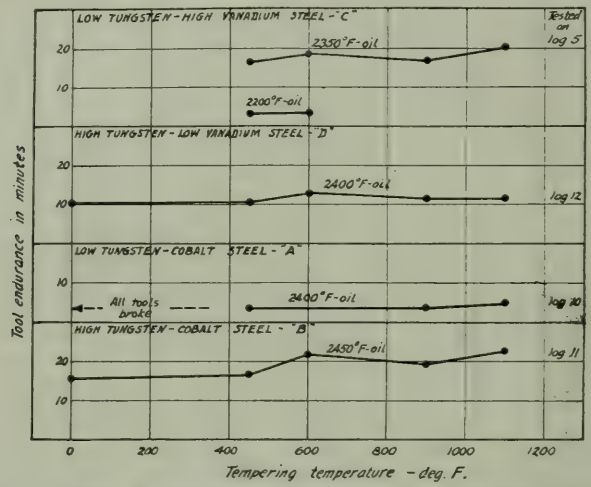


Fig. 2—Effect of tempering temperature on the endurance of four high-speed steels first quenched from various temperatures.
Steel compositions are given in Table I and properties of the test logs in Table II.

two steels without cobalt. While the authors have already pointed out that endurance tests cannot be used with certainty in comparing steels of nearly similar performance the consistent though small increases in samples tempered at 600 or 1100 degrees Fahr. over those tempered at 450, 900 degrees Fahr. or not at all is significant especially as these effects coincide with the small changes in hardness found by many investigators.

However, the most important reason for tempering between 600 and 1100 degrees Fahr. (providing the tools have been properly hardened) is not increased endurance but decrease in brittleness. This is of special importance in steels containing 13 per cent tungsten as shown by tool breakage noted in Table IV and confirmed by results of bend tests reproduced in Fig. 3.

In other words, high-speed steels subjected to severe service

have endurance characteristics of the high temperature treatment used in hardening and this is not modified to any great degree by any subsequent variations in tempering up to and including 1100 degree Fahr. This is well shown by the tests of low tungsten-high vanadium steel subjected to both low and high hardening heats and various tempering temperatures (Table IV) and indicates the misleading nature of discussions based solely on hardness deter-

Table IV

Effect of Tempering Temperature on the Endurance of Four High-Speed Tool Steels Hardened in Various Ways.

Steel No.	Tests made on log. No.	Heat treatment (a) High heat Temp. deg. Fahr.	Time in minutes	Tempering temp., degrees Fahr.	Tool endurance in minutes — 1st grind 1	2	3	4	Re-grind 1	2	3	4	Average all tests
C		Low tungsten-high vanadium steel											
	5	2350	2	450	14.6	B	16.7	B	....	20.8	20.3	10.0	16.5
				600	24.3	10.3	17.5	16.8	22.9	14.7	22.4	....	18.4
				900	13.8	14.8	20.6	11.3	19.5	17.0	23.8	11.2	16.5
				1100	17.0	16.7	25.6	11.6	23.4	16.3	36.5	14.9	20.2
		2200	2	450	2.1	7.2	6.5	1.6	1.9	1.2	3.4	0.5	3.0
				600	1.2	7.7	1.7	6.0	2.0	1.5	2.0	2.9	3.1
		2350	2	into lead at 1100 degrees for 30 min.	B	B	B	B	B	B	B	B	B
D		High tungsten-low vanadium steel											
	12	2400	1½	None	10.2	B	12.2	B	8.0	12.1	7.9	B	10.1
				450	9.7	14.1	8.8	10.3	12.6	B	7.3	....	10.5
				600	8.4	14.8	12.0	13.2	13.1	15.6	11.6	10.9	12.4
				900	11.8	9.7	9.2	8.0	12.8	11.5	....	16.2	11.3
				1100	17.0	10.1	11.0	11.3	8.2	14.2	8.6	13.1	11.7
A		Low tungsten-cobalt steel											
	10	2400	1½	None	B	B	B	B	B	B	B	B	B
				450	3.8	1.9	2.6	B	4.0	3.9	B	B	3.2
				900	3.2	4.3	3.0	4.0	3.9	3.6	2.6	4.6	3.6
				1100	4.0	5.1	3.9	5.8	4.3	4.0	4.9	4.3	4.5
B		High tungsten-cobalt steel											
	11	2450	1½	None	19.0	B	13.5	B	15.8	13.0	B	B	15.3
				450	12.1	15.0	21.3	....	17.3	15.0	13.8	23.4	16.8
				600	21.1	25.5	22.2	21.9	18.0	28.2	21.2	14.3	21.6
				900	15.1	17.4	17.2	23.5	19.9	21.5	19.3	18.5	19.0
				1100	27.8	20.6	22.6	24.6	24.9	18.2	20.7	22.0	22.7

(a) All tools placed in preheating furnace at 1400 degrees Fahr.; raised to 1600 degrees Fahr. and held 20 minutes; then introduced into the high-heat furnace at temperatures shown. They were quenched in Houghton's No. 2 soluble quenching oil and subsequently tempered for 30 minutes at various temperatures as indicated.

B—Tool broke.

mination which, as has repeatedly been shown. have no direct relation to tool performance.

While the data presented in Fig. 3 are self-explanatory attention should be called to the very high values for maximum fiber stress obtained in the bend tests of the high tungsten-low vanadium steel. In addition to being able to withstand higher stress than

the low tungsten-high vanadium steel greater deformation can be absorbed before failure will occur.

3. *Constitutional Changes in High-Speed Steels With Heat Treatment*

The very marked increase in endurance in high-speed steels with rise in quenching temperature is of both practical and theoretical interest especially as the lathe tests were so severe that the nose of each tool was raised to a red heat readily visible in diffused daylight, the temperature being certainly not less than 1400 de-

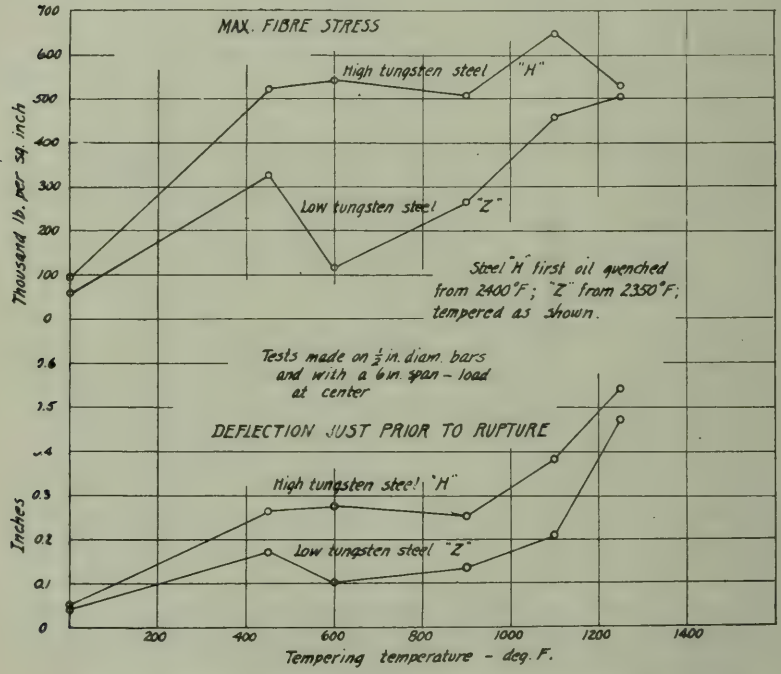


Fig. 3.—Effect of tempering temperature on the brittleness of hardened high-speed steels as shown by bend tests.

grees Fahr. In other words, the effective portion of the tool was operating at a temperature above that required to decompose the martensitic groundmass and, according to Shore and Brinell hardness determinations, is soft. It is therefore not surprising that variations in tempering temperature produced only minor changes in endurance and that tools showed performance generally charac-

teristic of the high temperature treatment to which they were originally subjected.

The constitutional changes in high-speed steels under varying thermal treatments have been studied by a number of investigators who have made use of hardness determinations, microscopic examinations, volume changes and magnetic and thermal analysis, etc., but it is improbable that any explanations so far advanced for the observed effects are wholly correct. For this reason any further data which might throw light upon the nature of the reactions involved should be of special interest.

Edwards and Kikkawa[6] consider that the variations in properties of high-speed steels with rise in quenching temperature are largely due to an increase in the amount of tungsten brought into solution for when low hardening temperatures were used for their high-speed steels the tempering properties approximated those of plain chromium steels. On the other hand, Honda and Murakami[7] believe that solution of the carbides is followed by a further reaction according to the following equation:

$$2\ Cr_4C \rightleftharpoons Cr_3C_2 + 5\ Cr$$

and that the higher the quenching temperature the more this change proceeds from left to right.

To throw light upon the changes which take place thermal analysis was made of samples first quenched from various high heat temperatures and the results are given in Fig. 4. Such tests have already been carried out by a number of investigators but in all cases which have been brought to the attention of the authors the heating curves subsequent to hardening have been restricted to temperatures below about 1700 degrees Fahr. In view of the well known ability of high-speed steels to cut while at red heat complete tempering or reversal of the changes which occur in the process of hardening cannot take place rapidly in the ranges already covered. It was therefore believed advisable to obtain thermal curves up to higher temperatures including 2100 degrees Fahr.

(6) C. A. Edwards and H. Kikkawa: "The Effect of Chromium and Tungsten upon the Hardening and Tempering of High-Speed Steels," *Journal*, Iron and Steel Institute, 92, 1915, part 2, page 6.

(7) K. Honda and T. Murakami: "On the Structural Constitution of High-Speed Steel Containing Chromium and Tungsten and the Effect of these Elements on its Hardening and Tempering," *Science Reports* of Tohoku Imperial University, 1st Series, 9, page 143 (1920).

Evidently a rise in the original quenching temperature from 2200 to 2500 degrees Fahr. causes one or more molecular or atomic rearrangements or, to express this somewhat differently, changes take place in the combinations of carbon, chromium, tungsten or vanadium in solid solution for the Ac_1 transformation found upon

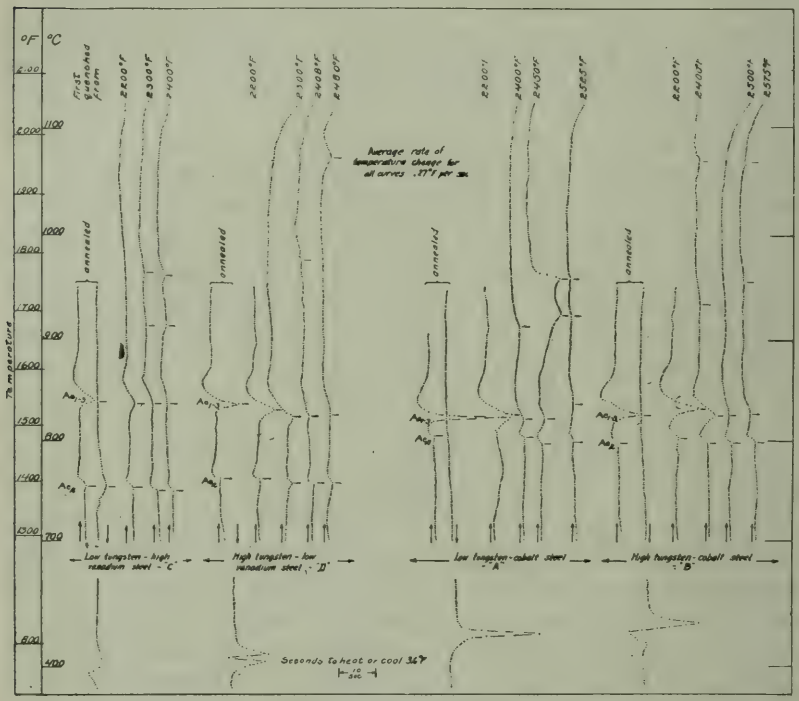

°F
°C
Temperature
annealed
Average rate of temperature change for all curves .17°F per sec.
Low tungsten - high vanadium steel - C
High tungsten - low vanadium steel - D
Low tungsten - cobalt steel - A
High tungsten - cobalt steel - B
Seconds to heat or cool 367

Fig. 4—Thermal analysis of high-speed steels first annealed or quenched from various high-heat temperatures. Steel compositions are given in Table I.

reheating the sample first quenched from 2200 degrees Fahr. is gradually suppressed and then split as the initial hardening temperature is raised. The intensity of this "normal" Ac_1 point decreases as that of the new points, which appear at higher temperatures, increases.

The changes accompanied by these thermal effects, shown in detail in Fig. 4, are undoubtedly related in part to the tungsten and not restricted to the chromium as intimated by Honda and Murakami for the highest point occurs at a much higher temper-

ature in both high-tungsten steels than in those containing low tungsten. However, a simple change in the proportion of tungsten in solution, as suggested by Edwards and Kikkawa, does not seem to be an adequate explanation. Under such conditions the "normal" Ac_1 should merely increase in intensity with the proportion of tungsten originally dissolved which, in turn, would increase with the high heat temperature and time in the initial hardening. A gradual elevation and widening of the heat effect might be observed but no such splitting as is shown in Fig. 4.

The marked increase in endurance in high-speed steels with rise in quenching temperature is therefore related to one or more atomic or molecular changes, probably of tungsten and possibly also of vanadium and chromium in solid solution, which take place between 2200 and 2500 degrees Fahr. Their reversal is sluggish as shown by the high temperatures at which the thermal effects occur on reheating and by the fact that hardened tools will, as in the described tests, operate for short periods at temperatures well above that at which the martensitic groundmass is decomposed. So-called red hardness is a function of these reactions and bears no relation to secondary hardening obtained when tempering at about 1100 degrees Fahr. Such tempering reduces brittleness by changing the constitution of the groundmass in hardened high-speed steels but it is the quantity and characteristics of the constituents formed at temperatures between about 2200 and 2500 degrees Fahr. that largely determines the tool endurance in severe service and resists the high temperature abrasion which "gutters" and wears away the nose of the tool and ultimately causes failure.

4. *Effect of time at high heat and manner of heating on tool endurance*

As the heat treatment of high-speed steels is now ordinarily carried out accurate control of temperatures is maintained but in many instances the time factor is left to the judgment of the furnace operator or tool hardener. The part played by temperature variations in both hardening and tempering have already been discussed and in order to show the effects of the time element tests were made of tools first heated in various ways and quenched from a given temperature or held in the high heat furnace for different intervals. Results are given in Tables V and VI.

It will be noted that tools held in the high heat furnace for 3 minutes at 2280 degrees Fahr. have an endurance of 12.2 minutes while those held for half this time at 2400 degrees Fahr. continued to cut under the same conditions of test for 16.1 minutes. The short time at the higher heat has given an increase of 32 per cent in endurance over the long time at the lower temperature whereas

Table V

Effect of Time at Various High-Heat Temperatures on the Endurance of High Tungsten-Low Vanadium Steel "D."

Preheat		High Heat (a)		Tool endurance in minutes (b)								
				1st Grind				Re-grind				Average of
Temp., deg. F.	Time in Min.	Temp., deg. F.	Time in Min.	1	2	3	4	1	2	3	4	all tests
1600	20	2280	3	11.6	11.4	10.8	21.2	12.7	10.3	7.7		12.2
1600	20	2400	50 sec.	6.6	6.8	10.3	9.6	8.5	6.1	8.8	5.1	7.7
1600	20	2400	1½	11.5	11.7	16.2	19.4	16.7	19.0	18.2	15.8	16.1

(a) All tools quenched in oil and subsequently tempered for 30 minutes at 1100°F.
(b) Tests made on log. No. 16.

in the first series of tests in which all tools were held for equal times at various high heat temperatures a change from 2280 to 2400 degrees Fahr. has increased tool endurance by 121 per cent. While these two series of tests were carried out on different test logs the observed variations are large enough to establish the importance of time at high heat in determining tool performance. Further confirmation is contained in Table VI for the tools which were not preheated but held in the high heat furnace at 2400 degrees Fahr. for 2¼ minutes are superior to those subjected to

Table VI

Effect of Manner of Heating on the Endurance of High Tungsten-Low Vanadium Steel "D"

Preheat		High heat (a)		Tool endurance in minutes (b)								
				1st Grind				Re-grind				Average of
Temp., deg. F.	Time in Min.	Temp., deg. F.	Time in Min.	1	2	3	4	1	2	3	4	all tests
None		2400	2¼	15.1	15.6	20.6	24.2	11.1	9.6	25.2	27.4	18.6
1400	20	2400	1½	13.8	5.6	8.2	....	19.5	18.3	10.7	11.0	12.4
1600	20	2400	1½	17.0	10.1	11.0	11.3	8.2	14.2	8.6	13.1	11.7
1700	20	2400	1½	13.7	9.8	11.2	11.6	13.8	...	...	14.0	12.3

(a) All tools quenched in oil and subsequently tempered for 30 minutes at 1100°F before test.
(b) Tests made on log. No. 12.

this high heat for a shorter time after preheating at various temperatures. No marked differences in performance are observed when the preheating temperature is varied from 1400 to 1700 degrees Fahr.

It may therefore be said that variations in the manner of

heating high-speed steels only affect tool endurance insofar as they change the time at which the tools are at the high heat temperature or, in cases where very short immersion is used, as they modify the maximum temperature attained by the working portions of the tool. The time at high heat is of prime importance for the longer the immersion in the high heat furnace at a given temperature (within limits) the higher will be the endurance. It is therefore necessary to control both time and temperature in order to obtain consistent results.

5. *Dimensional changes in heat treatment*

The foregoing discussions have been restricted to the effects of heat treatment upon lathe tool performance and the constitution of high-speed steels. Frequently, however, as in form cutters, taps dies, etc., control of dimensional changes becomes of considerable importance but there is a scarcity of accurate data relating to this question. The need for additional information is well emphasized by the apparent discrepancies in test results recently reported by Grossmann[8] and Spalding[9]. The latter stated that "it has been our general experience that a high-speed steel will shrink in hardening" whereas the former found length expansion in every case but careful consideration of test conditions in both investigations will show variations in or lack of control of variables which might readily account for the observed differences. For example, the preliminary annealing treatments and time at high heat temperatures which might largely affect the degree of solution of the various constituents, the molecular changes in the hardening operations and hence the volume changes are not described in detail.

The test specimens used in this investigation were of the form and dimensions shown in Fig. 5. Care was taken to have the ends as nearly parallel as possible by finishing all samples in a special chuck in a surface grinder. In all cases the test specimens were so marked that length and diameter measurements could be taken at approximately the same points before and after heat treatment.

As considerable oxidation takes place at the high heats

(8) M. A. Grossmann: "The Change in Dimensions of High-Speed Steels in Heat Treatment," *Transactions*, American Society for Steel Treating, Vol. 2, No. 8, page 691 (May, 1922).

(9) Discussion of paper by Grossmann, *Transactions*, American Society for Steel Treating, Vol. 2, No. 10, page 890 (July, 1922).

ordinarily used for high-speed steels the end surfaces were protected by steel caps as shown in Fig. 5. Whether this has an effect upon the observed changes is immaterial in this case as all samples were handled in the same manner and the results are therefore comparable.

Length changes were determined in hundred thousandths of

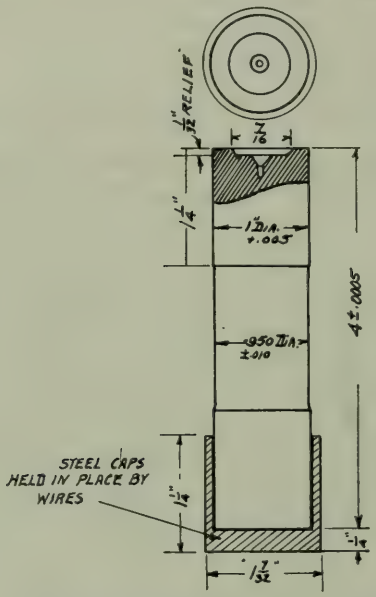


Fig. 5—Type of test specimen used in determining dimensional changes of high-speed steels under varying heat treatments.

an inch at four points, and diameter at two, with a Pratt & Whitney measuring machine. All determinations were made within a few hours after treatment by comparison with a standard chrome-steel block at temperatures between 20 and 22 degrees Cent.

In the heating and cooling of any steel for hardening constitutional changes take place which, as is well known, are accompanied by volume changes. However, in both operations as ordinarily carried out, heat transfer takes place through the metal surfaces and if either the heating or cooling is rapid for samples of appreciable size temperature gradients are established which introduce stresses in the metal. The magnitude and direction of these stresses appear to be functions of the chemical and physical constitution of

the steel, the size and shape of the piece, the temperature gradients which, in turn, are dependent on the temperature difference between the specimen and the heating unit and their relative thermal capacities, etc. If these stresses are induced at relatively high temperatures at which the steel is soft and plastic then flow results and a change in dimensions though not necessarily a change in volume is observed; if at relatively low temperatures where the steel is hard and more or less brittle and unable to deform readily severe stresses produce cracking.

The dimensional changes shown in subsequent Figures and Tables are the result of constitutional volume changes and the effects due to thermal gradients arising from rapid heating or cooling The latter which will be referred to as "distortion" are, of course, dependent to some degree upon the former but in a given set of tests the magnitude of each may be approximated by the method used in the work of the Gage Steel Committee[10]. The constitutional length changes may be approximated from changes in specific volume on the assumption that these effects take place equally in all directions. The difference between this and the total observed changes may then be taken as a measure of "distortion." This procedure has been followed in a number of cases to throw light upon the effects produced by several of the variables considered.

As shown in Table VII dimensional changes under a given hardening treatment may be greatly modified by variations in the original condition of the steel. For example, specimens A2 and A5 which were not specially annealed but treated in the "as received" condition increased in length upon quenching from 2300 degrees Fahr. whereas samples A-13 and A-20, which were first annealed and then quenched, decreased in length. As the hardening was the same in both cases, the observed variations must have been due in large part to the form and quantity of the various constituents originally in solution. This immediately suggests the desirability of a study of the annealing of high-speed steels for it should be possible to so vary preliminary treatments that pieces of given size and shape would show exceedingly small length changes upon hardening. However, it is not possible to practically eliminate changes in both length and diameter.

(10) Unpublished monthly progress reports from the Bureau of Standards to the "Gage Steel Committee," prepared by H. Scott.

Likewise dimensional changes may be modified to some extent by stresses induced in machining. This is shown in comparison of specimens A-13 and A-14 with A-18 and A-20. The former were first machined and then annealed while the latter were similarly annealed and then machined. Evidently machining stresses in the case cited tended to shorten the test specimens for upon relief an expansion took place which reduced in part the normal shrinkage observed in hardening. It is probable, however, that these effects will vary widely and cause either expansion or shrinkage

Table VII

Effect of Varying Conditions of Treatment upon Dimensional Changes in Hardening High-Speed Steel.

No.	Heat Treatment (steel A 34 of Table I.)	Dimensional changes in Inch x10⁴ Length	Diameter	Shore Hardness
	Machined and then annealed 2 hrs. at 1600 degrees Fahr.			
A 13	1600 degrees Fahr.-20 min.; 2300 degrees Fahr.-2½ min.; oil	− 9.2	+11.8	89
A 14	No preheat; 2300 degrees Fahr.-5 min.; oil	− 1.9	+11.8	91
	Annealed 2 hrs. at 1600 degrees Fahr. and then machined.			
A 20	1600 degrees Fahr.-20 min.; 2300 degrees Fahr.-2½ min.; oil	− 1.2	+11.0	90
A 18	No preheat; 2300 degrees Fahr.-5 min.; oil	− 0.3	+11.2	91
	As supplied by the mill.			
A 5	1600 degrees Fahr.-20 min.; 2300 degrees Fahr.-2¾ min.; oil	+17.6	+13.6	93
A 2	1600 degrees Fahr.-20 min.; 2300 degrees Fahr.-2½ min.; oil	+15.4	.....	90
A 7	No preheat; 2300 degrees Fahr.-5 min.; oil	+35.8	+10.0	95
A 3	No preheat; 2300 degrees Fahr.-4 min.; oil	−10.6	.....	92
A 2	No preheat; 2300 degrees Fahr.-4 min.; oil	− 2.8	+10.4	91

depending upon the exact conditions under which the specimens are prepared.

The effects of variation in high heat temperature and also time at high heat upon dimensional changes in hardening are shown in Table VIII and Fig. 6. It will be observed that both temperature and time are of prime importance in controlling dimensional changes for with increase in either a marked increase in length expansion occurs. Methods which include careful control of temperatures but disregard of the time factor will therefore not give consistent results and it is probable that many of the variations encountered in production in parts made from the same bars of steel are due to the practice of leaving control of time to the judgment of the furnace operator.

In order to throw further light upon the importance of the

time factor in hardening, a number of samples were preheated in various ways or not at all and dimensional changes noted. The results, together with approximation of the constitutional length changes and "distortion" are given in Table IX. Holding the samples in the high heat furnace for five minutes without preheating has not brought about as great a degree of solution of the constituents as half this time subsequent to the ordinary

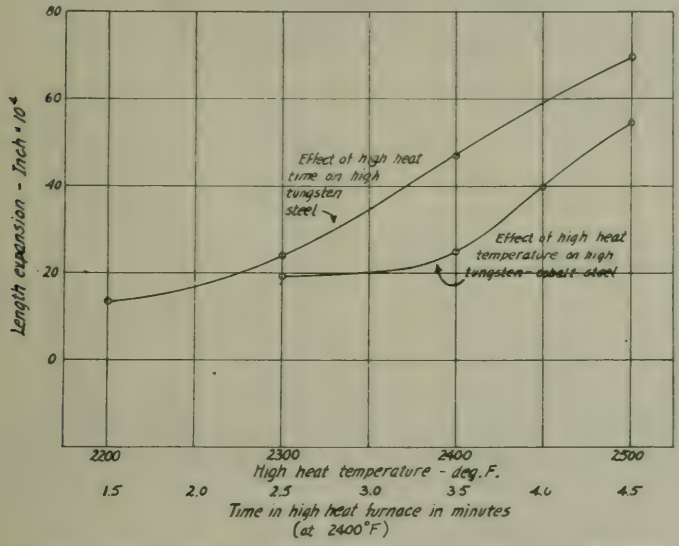


Fig. 6—Effect of high-heat temperature and time in the high-heat furnace at 2400 degrees Fahr. on the length changes of high-speed steels. Compositions of steels used in these experiments are given in Table I. The high-tungsten steel used is H and the cobalt steel is CC.

method of preheating at 1400 to 1700 degrees Fahr. Also in the latter case the distortion is in the nature of a shrinkage whereas when no preheating is used the effect of distortion is to elongate the sample. These variations which are due to the differences in the thermal stresses induced during heating and cooling are quite large and not difficult to explain. Distortion in the preheated specimens is largely due to the stresses induced in cooling as a very slow heating rate was used until the sample was introduced into the high heat furnace. The conditions obtaining in the rapid cooling in oil tend to shrink the sample. On the other hand introduction directly into the high heat furnace, without preheating, sets up large thermal gradients which induce stresses

of considerable magnitude that tend to elongate the outer shell of the cylinders where the length determinations were made. This heating effect is great enough to more than counterbalance the tendency to shrink during cooling so that the sum total of distortion effects in heating and cooling in this case is an expansion.

Table VIII

Effect of High-Heat Temperatures and Time on Dimensional Changes in Hardening 1" diam. x 4" Cylinders of High-Speed Steel.

High heat (a)		Dimensional changes in Inch x10⁴	
Temperature, degrees Fahrenheit	Time in minutes	Length	Diameter
High tungsten-cobalt steel "CC" of Table I.			
2350	2½	+22.8	+ 9.9
		+15.4	+ 6.5
Av.		+19.1	+ 8.2
2400	2½	+24.7	+ 5.1
2450	2½	+45.2	+ 6.2
		+38.6	+ 3.3
		+35.2	.....
Av.		+39.7	+ 4.8
2500	2½	+54.3	.....
High tungsten-low vanadium steel "H" of Table I.			
2360	1½	+13.2	+ 6.7
2400	2½	+27.8	+17.9
		+19.9	+14.7
Av.		+23.8	+16.3
2400	3½	+47.1	+14.6
		+46.6	+14.5
Av.		+46.8	+14.6
2400	4½	+69.5	+10.6

(a) Samples heated at less than 18 degrees Fahr., per minute to 1700 degrees Fahr.; held 20 minutes and introduced into high-heat furnace at temperatures shown; after holding for specified time they were oil quenched.

As previously stated all length changes were determined at four points near the circumference of the cylinders and measurements before and after heat treatment were made at approximately the same points. The results discussed are therefore representative of the average changes but it is to be noted that the cylinder ends, which were nearly parallel and moderately plane surfaces before hardening, showed warpage in all cases. This should not be confused with the term "distortion," as used in this report, which refers to that portion of the total length changes, measured at fixed points, which were caused by thermal gradients in heating and cooling.

The variations in dimensional changes encountered in hardening a given steel from one temperature are real for, as shown in Fig. 7, the differences are maintained after tempering at temperatures up to 1100 degrees Fahr. While the length change-tempering temperature curves are all parallel and show a decrease in the

expansion with rise in tempering temperature up to 900 degrees Fahr. and subsequently an expansion, only two pass through zero. The original length change in hardening has been obliterated in one when tempering at about 450 and in the other at 700 degrees Fahr. Tempering may therefore be used to reduce any length expansion or shrinkage obtained in hardening but it is only in

Table IX

Effect of Manner of Heating Upon Dimensional Changes in Hardening 1" Diam. x 4" Cylinders of High-Speed Steel.

No.	Heat treatment (a) Preheat, deg. F.	High heat deg. F.	Dimensional changes in Inch x10⁴ Length	Diameter	Change in Specific Volume, (b) Per cent	Length Distortion (c) in Inch x10⁴
	Low tungsten-high vanadium steel "Z"					
1	None	2350	+18.0	+ 2.8	+0.08	+ 7.3
2	1400	2350	+11.6	+ 7.2	+0.18	—12.4
	Low tungsten-high vanadium steel "A 34".					
3	None	2300	— 0.3	+11.2	+0.27	—36.3
4	1600	2300	— 1.2	+11.0	+0.30	—41.2
	High tungsten-low vanadium steel "H".					
5	None	2400	+55.9	+14.1	+0.36	+ 7.9
6	1700	2400	+23.8	+16.3	+0.38	—14.6
	High tungsten-cobalt steel "CC".					
7	None	2450	+66.2	+ 6.0	+0.40	+13.0
8	1400	2450	+40.2	+ 3.4	+0.52	—29.0
9	1700	2450	+36.9	+ 3.3	+0.50	—29.5

(a) Specimens raised at less than 18 degrees Fahr., per minute to specified preheating temperature, held 20 minutes and introduced into high-heat furnace. After 2½ minutes oil quenched. When no preheat was used the specimens were held 5 minutes in the high-heat furnace.

(b) These values calculated from density determinations before and after hardening.

(c) Length distortion is the difference between total observed changes (4th column) and those resulting from constituional changes in hardening; the latter may be approximated from per cent change in specific volume on the assumption that this effect is uniform in all directions.

certain cases that the length after treatment will approximate that of the original sample.

The foregoing discussion and the importance of the results may be summarized as follows:

(a) Length shrinkage or expansion may be produced in hardening a high-speed steel from a given temperature (if not too high) by varying the treatment prior to quenching. This includes both preliminary annealing and the manner of heating for hardening.

(b) However, the higher the quenching temperature and the time at high heat, within limits ordinarily encountered in commercial heat treatment, the greater will be the expansion or, with certain initial conditions of the metal, the less will be the shrinkage.

(c) Tempering up to 900 or 1000 degrees Fahr. subsequent

to hardening will reduce the original expansion or increase the shrinkage but the final length will approximate the original only in certain cases. The tempering which will produce this ideal condition will vary widely in a given steel depending upon the previous history of the samples.

(d) For consistent results with respect to dimensional

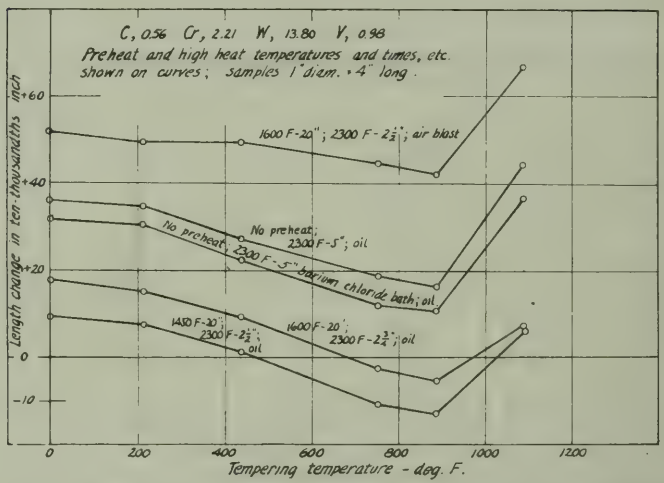


Fig. 7—Effect of tempering on the length changes of a high-speed steel first hardened in various ways. Form of test specimen used is given in Fig. 5.

changes the time factor in all heat treatment operations as well as the temperature must be under complete control.

The practical value of having detailed information of the type discussed has been emphasized in a case recently brought to the attention of the authors. Hobs for cutting hard steel were required in a plant without suitable grinding equipment. Carbon steels were unsatisfactory for the work to be done while high-speed steels, because of their exceptional resistance to fracture when subjected to transverse bending stresses, appeared most desirable With complete information regarding the effects of various preliminary treatments, the manner of heating, the high heat temperature and time, etc., upon dimensional changes in heat treatment it would have been comparatively easy to keep the length changes below a prescribed minimum so that final grinding could be omitted.

6. *Effect of Variation in Cutting Speed on the Performance of Various High-Speed Steels*

Considerable attention was paid in an earlier report[11] to the comparative endurance of various types of high-speed steel subjected to severe service in cutting nickel steel forgings at between 60 and 67 feet per minute. However, the high frictional

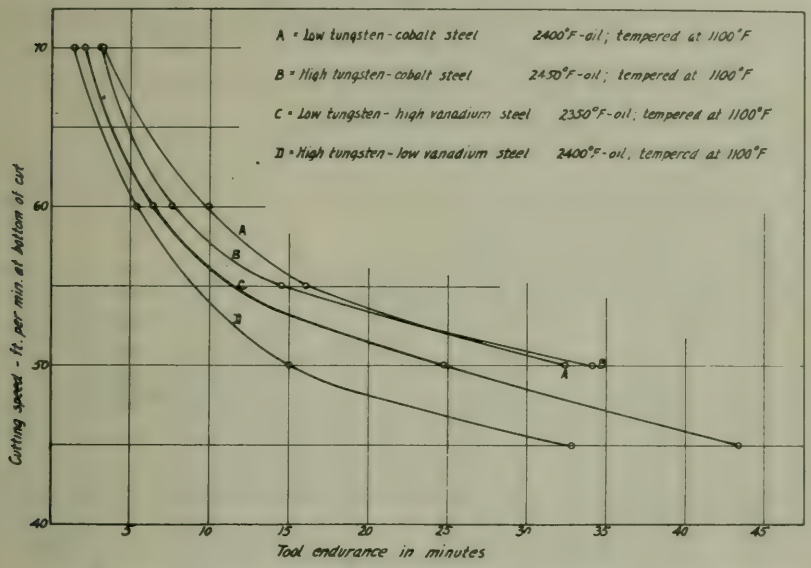


Fig. 8—Effect of cutting speed on the endurance of four types of high-speed steel used on nickel steel forgings. Details of test results are given in Table X; properties of test logs in Table II, and tool angles, depth of cut, etc., in the text at the beginning of this report.

temperatures produced in these tests are rarely if ever encountered in commercial work as coolants are used or the tools are not required to operate with heavy cuts and feeds at such high speeds. Comparisons based on severe duty might not necessarily hold under more moderate service, as indicated by tests already described in which varying feeds were employed, so that all four steels considered in this report were run on one set of test logs with fixed feed and depth of cut and speeds varying from about 45 to 70 feet per minute. The results obtained are shown in detail in Table X and reproduced graphically in Fig. 8.

The general shape of the cutting speed—endurance curves

(11) Refer to (1).

is the same for the four steels and quite similar to the data presented for original high-speed steels by Taylor[12]. However, the relative performance of steels A, B, C and D varies at different cutting speeds as shown in Table XI, though the general order of superiority does not change except in the case of steels A and B at low cutting speeds but this cannot be taken too seriously

Table X

Effect of Cutting Speed on the Endurance of Four High-Speed Steels.

Cutting Speed ft. per min. at bottom of cut	Tool Endurance in Minutes — 1st grind — On log. 13		On log. 10		Re-grind — On log. 15		On log. 14		Average all tests
	1	2	3	4	1	2	3	4	
Low tungsten-high vanadium steel "C". 1600 degrees Fahr.-20 min.; then 2350 degrees Fahr. 1½ min. oil; tempered 1100 degrees Fahr.-30 min.									
70	2.8	2.5	2.4	2.6	2.3	2.0	1.5	1.8	2.2
60	8.0	2.5	12.6	8.4	5.1	3.8	6.5	4.6	6.4
50	22.6	29.0	30.6	30.3	23.0	24.5	23.3	14.3	24.7
45	37.5	35.6	63.1	68.2	27.8	23.1	58.3	33.2	43.4
High tungsten-low vanadium steel "D". 1600 degrees Fahr.-20 min.; then 2400 degrees Fahr., 1½ min. oil; tempered 1100 degrees Fahr.-30 min.									
70	2.0	1.1	1.6	1.5	1.2	1.5	0.6	1.7	1.4
60	5.5	10.3	3.3	6.5	3.4	5.3	3.0	5.4	5.3
50	....	....	17.1	20.4	15.6	11.5	11.0	14.2	15.0
45	38.5	42.1	26.6	48.8	20.0	44.3	18.5	23.2	32.8
40	90.5	76.0	....	....	....	....	....	....	(83.2)
Low tungsten-cobalt steel "A". 1600 degrees Fahr.-20 min.; then 2400 degrees Fahr.-1½ min. oil; tempered 1100 degrees Fahr.-30 min.									
70	3.0	5.4	3.5	3.0	2.9	3.8	2.6	2.1	3.3
60	6.4	7.4	9.8	15.7	13.0	6.5	9.9	10.4	9.9
55	15.0	11.2	23.3	29.7	14.0	10.0	12.2	13.1	16.1
50	19.6	34.9	48.8	48.9	25.9	27.3	27.3	26.3	32.4
High tungsten-cobalt steel "B". 1600 degrees Fahr.-20 min.; then 2450 degrees Fahr.-1½ min. oil; tempered 1100 degrees Fahr.-30 min.									
70	3.3	4.5	2.9	3.8	2.3	2.7	2.2	2.9	3.1
60	5.3	5.4	10.4	14.8	8.7	8.5	2.9	4.8	7.6
55	13.6	9.1	17.3	17.9	8.6	16.7	14.5	18.8	14.6
50	50.0	23.6	45.6	40.2	29.9	21.0	29.2	....	34.2

for the authors have already pointed out that the breakdown test is not to be relied upon for comparisons of steels having nearly similar endurance.

It likewise appears from Fig. 8 that curve A is more nearly paralled to C (low-tungsten steels with and without cobalt) than to the other curves and B to D (high-tungsten steels with and without cobalt). It is true that these differences are small but are worthy of attention as they are consistent with other effects already described which show that low-tungsten steels have somewhat different properties than those containing high tungsten; the addition of about 3.5 per cent cobalt modifies

(12) F. W. Taylor: "On the Art of Cutting Metals," *Transactions*, American Society of Mechanical Engineers, 1906.

these properties but does not appreciably change the characteristics of the two types.

As shown in Fig. 8 high-speed steels containing cobalt have much greater endurance at all cutting speeds than the plain chromium-tungsten-vanadium steels. Under the most severe service the low tungsten-cobalt type is superior to the high tungsten-cobalt steel but at the lowest speeds both have comparable endurance. The choice between these two, under such conditions, would therefore depend upon other factors. For example, it

Table XI

Comparisons of Various Types of High-Speed Steel on the Basis of the "Breakdown" and "Taylor" Tests. (a)

Steel	Cutting speed, ft. per min. at bottom of cut	Tool Endurance in minutes	Relative Performance as per cent of steel "A"	Order of Superiority
"Taylor Test"				
A—Low tungsten-cobalt	53.6	20	100	1
B—High tungsten-cobalt	53.2	20	99.2	2
C—Low tungsten-high vanadium	51.3	20	95.7	3
D—High tungsten-low vanadium	48.2	20	90.0	4
"Breakdown Test"				
A—Low tungsten-cobalt	70	3.3	100	1
B—High tungsten-cobalt	70	3.1	93.9	2
C—Low tungsten-high vanadium	70	2.2	66.7	3
D—High tungsten-low vanadium	70	1.4	42.4	4
A—Low tungsten-cobalt	60	9.9	100	1
B—High Tungsten-cobalt	60	7.6	75.7	2
C—Low tungsten-high vanadium	60	6.4	64.6	3
D—High tungsten-low vanadium	60	5.3	53.5	4
A—Low tungsten-cobalt	50	32.4	100	2
B—High tungsten-cobalt	50	34.2	105.6	1
C—Low tungsten-high vanadium	50	24.7	76.2	3
D—High tungsten-low vanadium	50	15.0	46.3	4

(a) For details of test results from which these computations were made refer to Table 10.

has already been shown (refer to Section III-2) that low tungsten steels (with or without cobalt additions) are more brittle than the high tungsten types but require lower hardening heats for best performance. Thus in cases where brittleness is of prime importance the high tungsten cobalt steel B, would be preferred; in cases where minimum oxidation and a clean surface on the treated tool is desired the low tungsten-cobalt steel has a decided advantage. In any case the choice would be dependent upon a number of factors in addition to endurance which have been discussed throughout various sections of this report.

It will also be noted that the endurance of the low tungsten-high vanadium steel is much greater than that of the high tungsten-low vanadiaum type at any of the speeds considered. This

is in agreement with and supplements results obtained in the authors' previous tests with larger tools and requires no further comments except to call attention to the fact that the heat treatments used for the several types of steels in the present instance were first shown to produce the best tool performance in severe service.

As the order of superiority does not change except in one case in which two of the steels show almost identical endurance, average performance ratings may be computed. These are based on individual ratings at 70, 60 and 50 feet per minute cutting speed, which have been expressed as a percentage of the best steel in each case, and are as follows:

	Per Cent
Low tungsten-cobalt steel-A	98
High tungsten-cobalt steel-B	90
Low tungsten-high vanadium steel-C	68
High tungsten-low vanadium steel-D	47

a. Comparison of the "Breakdown" and "Taylor" tests

While the described tests were made primarily to determine effects of cutting speeds upon tool endurance the results shown in Fig. 8 give an opportunity to compare the "Breakdown" and "Taylor" tests for high-speed steels. The latter, as is well known, consists in determining the cutting speed, under otherwise fixed conditions of feed, depth of cut, tool angles, etc., which will cause tool failure in exactly twenty minutes in place of choosing a fixed speed, as in the authors' tests, and determining the tool's endurance.

It has been claimed[13] that no difficulty is encountered in checking results on duplicate tools within five per cent by Taylor's method though little or no published experimental data, in addition to Taylor's work, have been presented to establish these limits. It is a fact, however, that greater uniformity in results will be obtained in all tests in which tool failure occurs in from 15 to 30 minutes than is the case with shorter or longer endurance and the reasons for this are fully discussed in Taylor's original report and need not be repeated. It is further claimed that while the Taylor test is more troublesome in operation, fewer tools are required to

(13) Discussion of report "Lathe Breakdown Tests of Some Modern High-Speed Tool Steels," *Transactions*, American Society for Steel Treating, Vol. 3, No. 9, page 956 (June, 1923).

obtain representative comparisons on account of this greater uniformity with the net result of a saving in time.

The summary contained in Table XI, which is based on results given in Fig. 8 shows that in general the order of superiority of the four steels tested is the same but their relative performance varies widely when comparisons are based on the Taylor or breakdown tests.

An ideal test would, of course, enable quick determination of the performance of tools or steels before they are placed in actual service and should give an accurate index of what will then be observed but the Taylor test fails in this respect on account of the variations cited. Steels A and D, for example, have respective performance ratings of 100 and 90 per cent in the Taylor test but if these steels were later placed in service under such conditions that failure in A would occur in about 30 minutes steel D would cut for less than half this time and actually have but half of the expected endurance.

The authors hold no brief for or against either type of test for both have found wide application and are of benefit when properly used. However, both types have limitations; those of the breakdown test were described in an earlier report, already referred to, while some of the characteristics of the Taylor test have here been discussed. One of the principal advantages of the latter is the uniformity in test results and the certainty that duplication can readily be obtained on the same materials at any time subsequent to the original test, even with steels of nearly similar performance. On the other hand it is much more troublesome to carry out and the comparisons obtained do not necessarily represent what may be expected in actual service. It therefore appears that the only positive indication at the present time of just what tools will do is to place them in service in the shop. This cannot be wholly replaced by the "Taylor" or "Breakdown" tests but much worthwhile information of practical value can be obtained by careful interpretation and correct application of results obtained by either method.

7. *"Flaky" fractures in high-speed steels*

The attention of the authors has occasionally been called to the occurrence in both annealed and hardened high-speed steels

of a course crystalline type of fracture (as contrasted with the usual more or less silky "porcelainic" appearance) which was previously referred to[14] as a "flaky" or "fish-scale" fracture. This condition, which is shown in various degrees in Figs. 9 and 10, has been observed in bar stock after the first hardening; in lathe, planer and shaper tools after frequent dressing and rehardening and in one recent case, in a purchased tool. It may also be produced intentionally by repeated quenching. Since the occurrence of this type of fracture has usually been associated with brittleness, the desirability of studying the properties of so-called "flaky" steel in heat treatment and possible methods of elimination becomes apparent.

"Flaky" fractures may be readily produced in any ordinary high-speed steel by repeated quenching from 2200 degrees Fahr. or higher temperatures as shown in Table XII but development of this characteristic appearance is independent of the time at high heat and, as far as the authors have been able to determine, of the manner of breaking the samples. The intensity of the "flake" increases with the hardening temperature and the number of quenching treatments up to five; also the "flakes" are larger and take on a more decided appearance in low tungsten than in high-tungsten steels similarly treated but in general the number of quenching treatments required to produce a given intensity will vary in different heats of the same type composition.

However, "flake" will not be produced by repeated quenching if the steel is annealed between successive treatments. Therefore in normal shop practice "flaky" steel may be produced through the hardening of long lengths of lathe, shaper and planer tools followed by dressing operations in which only part of the previously hardened steel is heated to annealing temperatures which would ordinarily prevent its occurrence.

The endurance of high-speed steel, intentionally "flaked" by repeated quenching, is in general similar to that of the same steel with a normal fracture but a series of lathe tests showed a much greater degree of brittleness and a tendency toward erratic results Its elimination is, therefore, greatly to be desired.

While the prevention of "flaky" fractures produced in heat treating is ordinarily a simple matter, when once produced, their

(14) Refer to (1).

Table XII

Production of "Flaky" Fractures in a High Tungsten-Low Vanadium Steel.

	Hardening					Annealing				Rehardening					
	Preheat		Quenching							Preheat		Quenching			
Bar No.	Temp. degrees Fahr.	Time min.	Temp. degrees Fahr.	Time min.	Medium	Temp. degrees Fahr.	Time min.	Cooling Medium	No. of Treatments	Temp. degrees Fahr.	Time min.	Temp. degrees Fahr.	Time min.	Medium	Fracture
X122-69	1600	20	2200	1 3/4	Oil				1						Clear
70	1600	20	2200	1 3/4	Oil				2						Clear
71	1600	20	2200	1 3/4	Oil				3						Slight Flake
72	1600	20	2200	1 3/4	Oil				4						Moderate Flake
73	1600	20	2200	1 3/4	Oil				5						Strong Flake
74	1600	20	2200	1 3/4	Oil				6						Strong Flake
13	1600	20	2300	2	Oil				1						Clear
15	1600	20	2300	2	Oil				2						Clear
17	1600	20	2300	2	Oil				3						Moderate Flake
19	1600	20	2300	2	Oil				4						Strong Flake
21	1600	20	2300	2	Oil				5						Strong Flake
23	1600	20	2300	2	Oil				6						Strong Flake
2	1600	20	2300	3	Oil				2						Clear
7	1600	20	2300	10	Oil				1						Clear
3	1600	20	2300	2	Oil				1	1650	20	2500	2	Oil	Clear
54	1600	20	2450	1 3/4	Oil				1						Clear
55	1600	20	2450	1 3/4	Oil				2						Clear
56	1600	20	2450	1 3/4	Oil				3						Strong Flake
57	1600	20	2450	1 3/4	Oil				4						Strong Flake
58	1600	20	2450	1 3/4	Oil				5						Strong Flake
4	1600	20	2500	2	Oil				1						Clear
5	1600	20	2500	2	Air				1						Clear
6	None		2500	2 1/2	Oil				1						Clear
11	None		2500	3 3/4	Oil				1						Clear
9	1600	20	2500	6	Oil				1						Clear
59	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 1	1600	20	2300	1 3/4	Oil	Clear
60	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 2	1600	20	2300	1 3/4	Oil	Clear
61	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 3	1600	20	2300	1 3/4	Oil	Clear
63	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 4	1600	20	2300	1 3/4	Oil	Clear
65	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 5	1600	20	2300	1 3/4	Oil	Clear
67	1600	20	2300	1 3/4	Oil	1650	60	Fce	(a) 6	1600	20	2300	1 3/4	Oil	Clear

(a) Refers to number of combined quenching and annealing treatments.

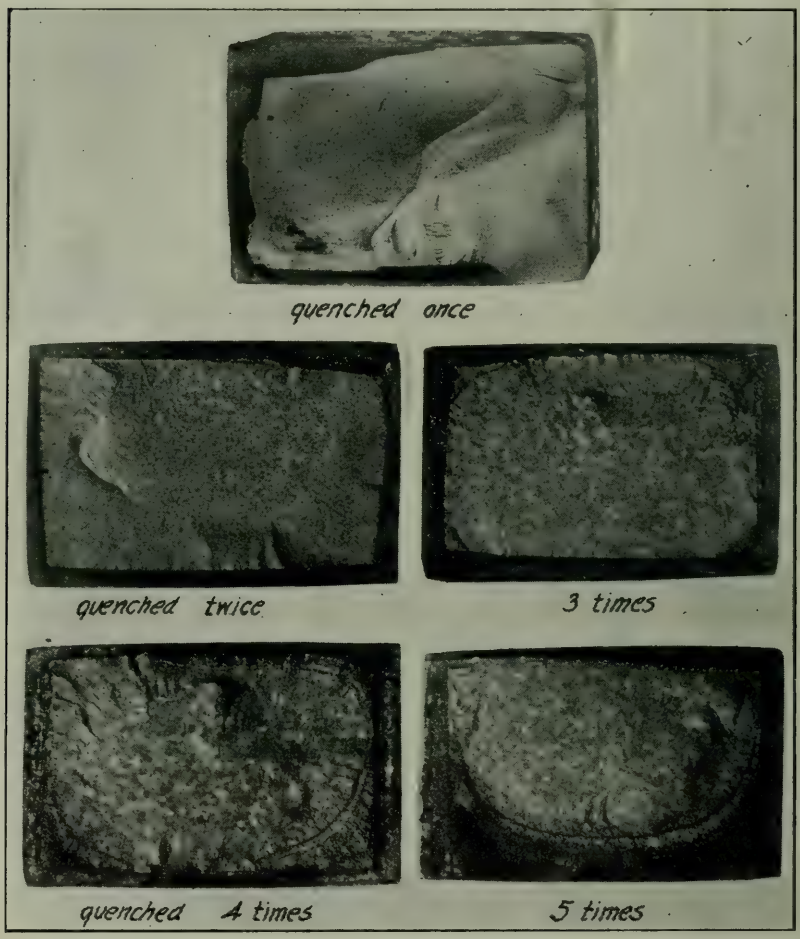


Fig. 9—Photographs of "flaky" fractures in low tungsten-high vanadium high-speed steel produced by repeated quenching from 2300 degrees Fahr. without intermediate annealing. Magnification about 2½.

elimination becomes most difficult for as shown in Table XIII, single and repeated annealing treatments, with many time-temperature combinations, have not been completely effective. No visible reduction in the intensity of this peculiar crystalline structure was observed until annealing was carried out at temperatures above 1600 degrees Fahr. The most complete removal was obtained with two successive annealing treatments at 1750 degrees Fahr. or with

three at 1650 degrees Fahr. (in either case the furnace cooling need not be carried below about 1100 degrees Fahr.

Since annealing alone is an ineffective remedy experiments were carried out in which forging and annealing were combined. The details of these tests are given in Table XIV.

Reductions in cross-sectional area of approximately twenty per cent when applied in conjunction with a 1600 degree Fahr. anneal prior and also subsequent to forging cause but a slight

Table XIII

Effect of Annealing on a High Tungsten-Low Vanadium Steel possessing "Flaky" Fracture.

NOTE: All samples hardened 4 times as follows: preheated at 1600 degrees Fahr. (20 min.), transferred to furnace at 2300 degrees Fahr. (1¾ min.) and quenched in oil. Re-hardening (after annealing) consisted in one repetition of this treatment.

Bar No.	Annealing —First— Temp. degrees Fahr.	Time min.	—Second— Temp. degrees Fahr.	Time min.	—Third— Temp. degrees Fahr.	Time min.	—Fourth— Temp. degrees Fahr.	Time min.	Fracture after Rehardening
A 122-81	(a)450	30	....	..	..	..	..	.	Strong Flake
85	(a)1100	30	....	..	..	..	..	.	Strong Flake
86	(a)1250	30	....	..	..	..	..	.	Strong Flake
A 119-1	1400	60	....	..	..	..	..	.	Strong Flake
A 122-34	1500	60	....	..	..	..	..	.	Strong Flake
40	1600	60	....	..	..	..	..	.	Strong Flake
32	1650	60	....	..	..	..	..	.	Moderate Flake
44	1650	180	....	..	..	..	..	.	Moderate Flake
42	1650	240	....	..	..	..	..	.	Moderate Flake
88	1800	60	....	..	..	..	..	.	Moderate Flake
A 119-2	1550	60	1550	60	..	..	..	.	Strong Flake
3	1650	60	1550	60	..	..	..	.	Moderate Flake
A 122-46	1650	60	1650	60	..	..	..	.	Moderate Flake
38	1650	120	1650	60	..	..	..	.	Moderate Flake
45	1650	180	1650	60	..	..	..	.	Moderate Flake
43	1650	240	1650	60	..	..	..	.	Moderate Flake
A 119-4	1750	60	1550	60	..	..	..	.	Moderate Flake
6	1750	60	1650	60	..	..	..	.	Moderate Flake
A 122-80	1750	60	1750	60	..	..	..	.	Slight Flake
A 119-5	1850	60	1550	60	..	..	..	.	Moderate Flake
7	1850	60	1650	60	..	..	..	.	Moderate Flake
A 122-50	1650	60	1650	60	1650	60	..	.	Slight Flake
48	1650	(b)10	1650	(b)10	1650	10	..	.	Slight Flake
A 119-8	1650	(c)20	1650	(c)20	1650	(c)20	1650	30	Slight Flake

All samples furnace cooled to nearly room temperature in annealing except in special cases noted

(a) Drawing operation followed by air cooling—no re-hardening treatment given.

(b) Furnace cooled to 1175 degrees Fahr.

(c) Furnace cooled to 1100 degrees Fahr.

diminution in the intensity of the "flake" which is produced in rehardening. This treatment is most effective for the low tungsten-high vanadium steel, somewhat less so for the high tungsten-cobalt steel and is of practically no value in the case of the high tungsten-low vanadium steel. Fifty to sixty per cent forging reduction is more effective in removing the "flaky" fracture, and is apparently less dependent upon the co-employment of annealing treatments than twenty per cent forging reduction. In

Table

Effect of Forging and Annealing on Several Types

Bar No.	Dia. of Bar in.	Hardening: Preheat Temp. degrees Fahr.	Preheat Time min.	Quenching Temp. degrees Fahr.	Quenching Time min.	Quenching Medium	No. of Treatments	Annealing Temp. degrees Fahr.	Annealing Time min.	Forging Reduction percent of area	Annealing Temp. degrees Fahr.
Z3	1⅛	1600	20	2300	4	Oil	4	1600	120	21	1600
Z5	1⅛	1600	20	2300	4	Oil	4	1600	120	(a)55	1600
Z2	1⅛	1600	20	2300	4	Oil	4	1600	120	21	None
Z4	1⅛	1600	20	2300	4	Oil	4	1600	120	(a)55	None
Z7	1⅛	1600	20	2300	4	Oil	4	None	.....	21	1600
Z9	1⅛	1600	20	2300	4	Oil	4	None	.....	(a)55	1600
Z6	1⅛	1600	20	2300	4	Oil	4	None	.....	21	None
Z8	1⅛	1600	20	2300	4	Oil	4	None	.....	(a)55	None
H3	1⅛	1600	20	2400	(d)5½	Oil	4	1600	120	21	1600
H5	1⅛	1600	20	2400	(d)5½	Oil	4	1600	120	55	1600
H2	1⅛	1600	20	2400	(d)5½	Oil	4	1600	120	21	None
H4	1⅛	1600	20	2400	(d)5½	Oil	4	1600	120	55	None
H7	1⅛	1600	20	2400	(d)5½	Oil	4	None	.....	21	1600
H9	1⅛	1600	20	2400	(d)5½	Oil	4	None	.....	55	1600
H6	1⅛	1600	20	2400	(c)5½	Oil	4	None	.....	21	None
H8	1⅛	1600	20	2400	(d)5½	Oil	4	None	.....	55	None
C2	(e)1 1/16	1600	20	2400	5	Oil	3	1600	120	22	1600
C8	(e)1 1/16	1600	20	2400	5	Oil	3	1600	120	58	1600
C1	(e)1 1/16	1600	20	2400	5	Oil	3	1600	120	22	None
C7	(e)1 1/16	1600	20	2400	5	Oil	3	1600	120	58	None
C3	(e)1 1/16	1600	20	2400	5	Oil	3	None	.....	22	1600
C4	(e)1 1/16	1600	20	2400	5	Oil	3	None	.....	58	1600
C5	(e)1 1/16	1600	20	2400	5	Oil	3	None	.....	22	None
C6	(e)1 1/16	1600	20	2400	5	Oil	3	None	.....	58	None

(a) Reduced 20% and cooled; reduced 35% additional and cooled.
(b) Tough character of fracture concealed any possible "flake."
(c) Power off on second quench—temperature dropped—in furnace 8 min.
(d) First quench 6 min.
(e) Fine machine finish.

XIV

of High-Speed Steel Possessing "Flaky" Fracture.

aling Time min.	Fracture	Total Forging Reduction per cent of area	Annealing Temp. degrees Fahr.	Annealing Time min.	Rehardening — Preheat Temp. degrees Fahr.	Rehardening — Preheat Time min.	Rehardening — Quenching Temp. degrees Fahr.	Rehardening — Quenching Time Min.	Rehardening — Quenching Medium	Fracture
120					1600	20	2300	4	Oil	Very Slight Flake Center
	(b)				1600	20	2300	3½	Oil	Moderate Flake
120	Doubtful		1900	120	1600	20	2300	3	Oil	Trace of Flake
		80	1600	120	1600	20	2300	2	Oil	Clear
					1600	20	2300	4	Oil	Strong Flakes varies center to surface
					1600	20	2300	3½	Oil	Slight Flake
	Slight Flake		1900	120	1600	20	2300	2¼	Oil	Clear
		80	1600	120	1600	20	2300	2	Oil	Clear
120					1600	20	2300	4	Oil	Strong Flake
	(b)				1600	20	2300	3½	Oil	Slight Flake localized
120	Doubtful		1900	120	1600	20	2300	2	Oil	Trace of Flake
		80	1600	120	1600	20	2300	2	Oil	Clear
					1600	20	2300	4	Oil	Strong Flake
					1600	20	2300	3½	Oil	Slight Flake all over
	Strong Flake		1900	120	1600	20	2300	2	Oil	Clear
		80	1600	120	1600	20	2300	2	Oil	Clear
120					1600	20	2400	4½	Oil	Strong Flake localized
					1600	20	2400	3½	Oil	Strong Flake
120	Mod. Flake		1900	120	1600	20	2400	2	Oil	Trace of Flake
		80	1600	120	1600	20	2400	2	Oil	Trace of Flake
					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3½	Oil	Strong Flake
	Strong Flake		1900	120	1600	20	2400	2	Oil	Trace of Flake
		80	1600	120	1600	20	2400	2	Oil	Trace of Flake
120					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3½	Oil	Very Slight Flake Center
120	Clear		1900	120	1600	20	2400	2	Oil	Clear
		80	1600	120	1600	20	2400	2	Oil	Trace of Flake
					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3½	Oil	Strong Flake
	Strong Flake		1900	120	1600	20	2400	2	Oil	Trace of Flake
		80	1600	120	1600	20	2400	2	Oil	Trace of Flake
120					1600	20	2400	4½	Oil	Moderate Flake Center
					1600	20	2400	3	Oil	Very Slight Flake Center
120	Clear		1900	120	1600	20	2400	1¾	Oil	Clear
		83	1600	120	1600	20	2400	1¾	Oil	Clear
					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3	Oil	Very slight Flake
	Slight Flake		1900	120	1600	20	2400	1¾	Oil	Clear
		83	1600	120	1600	20	2400	1¾	Oil	Clear
120					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3	Oil	Slight Flake one side
120	Clear		1900	120	1600	20	2400	1¾	Oil	Clear
		83	1600	120	1600	20	2400	1¾	Oil	Clear
					1600	20	2400	4½	Oil	Strong Flake
					1600	20	2400	3	Oil	Strong Flake
	Strong Flake		1900	120	1600	20	2400	1¾	Oil	Clear
		83	1600	120	1600	20	2400	1¾	Oil	Clear

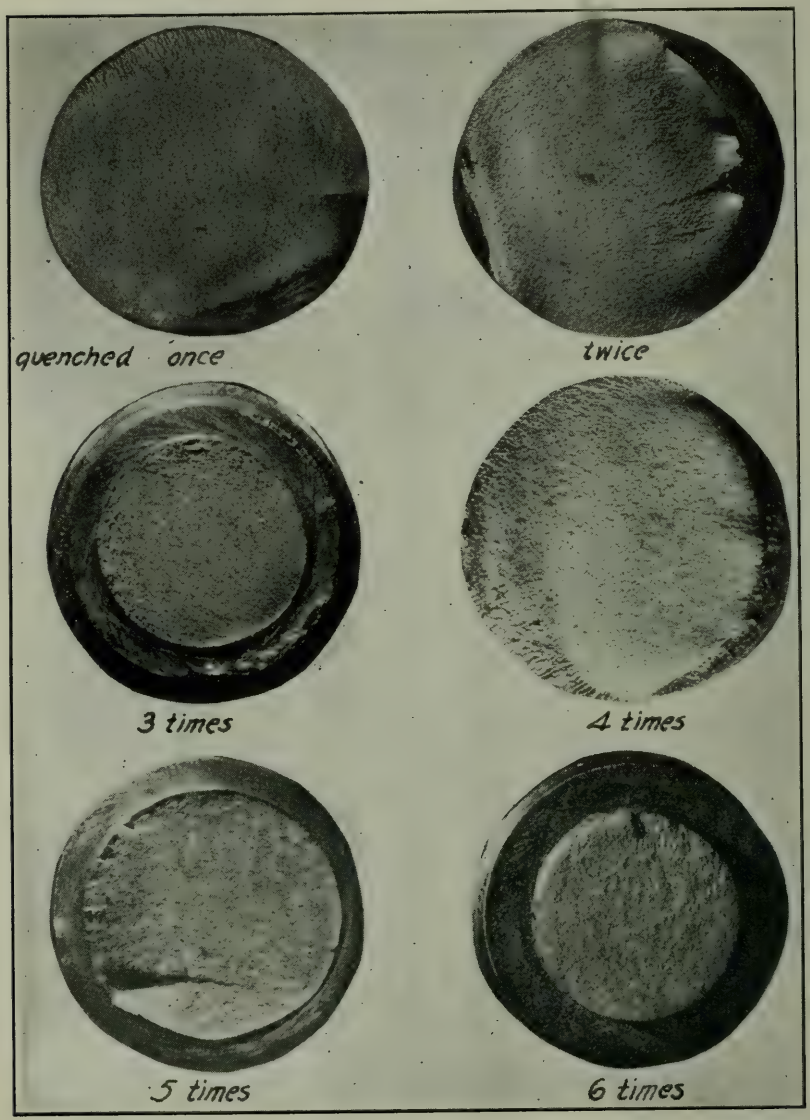


Fig. 10—Photographs of "flaky" fractures in high tungsten-low vanadium high-speed steel produced by repeated quenching from 2300 degrees Fahr. without intermediate annealing. Magnification about 2½. Note that the "flake" is not as pronounced as that in the low tungsten-high vanadium steel under the same heat treatments.

this case also the "flake" persists to a greater degree in the high tungsten-low vanadium steel than in the others. Eighty per cent forging reduction followed by annealing at 1600 degrees Fahr. or fifty to sixty per cent forging reduction followed by annealing at 1900 degrees Fahr. removes all evidences of "flaky" fracture or at most leaves a mere trace of the previous condition; the removal is most complete in the high tungsten-cobalt steel and least in the high-tungsten-low vanadium steel.

Thus, forging combined with annealing is an effective remedy for "flake" while even complicated annealing treatments can at best minimize this undesirable fracture.

It is questionable whether the remedial methods described could be applied except in cases where conversions into smaller tools is permissible for a relatively large amount of hot working is required. Prevention of "flake" is much more simple than its elimination and consists, under normal shop practice, of annealing all tools prior to rehardening.

In general the higher the reduction in forging the lower can be the annealing temperatures to effect a cure. It is also of interest to note that the high tungsten-low vanadium steel offers the greatest resistance to the formation of "flake" and likewise to its elimination when once produced.

IV. General Discussion and Conclusions

One of the outstanding features developed in this investigation is the importance of the time factor in the heat treatment of high-speed steels. Special emphasis is placed on this as the customary methods of treatment adopted by the industry in general include accurate control of temperatures in hardening but leave the time to the judgment of the operator. While excellent results have been obtained in many respects under such conditions it is improbable that anyone can so regulate operations day after day, by obesrving the appearance of tools or "sweating" produced in hardening, that desired uniformity in results can be obtained in all cases. Accurate control of both time and temperature with suitable instruments is necessary to guarantee consistent results.

The tests made also throw interesting light upon several factors to be considered in the selection of steels for specific service. It has been shown that high-tungsten steels require higher hardening

heats to produce maximum endurance than do the steels low in tungsten and that the addition of cobalt raises the required hardening temperature in both types and thus increases the oxidation obtained in heat treatment. However, the former are not as brittle as the latter.

In cases where both brittleness and the surface condition of the tool following treatment are unimportant the relative merits of the four steels may be considered to be approximately as given in the last paragraph of Section III-6. When brittleness is to be avoided but oxidation is unimportant the high tungsten-cobalt steel has a decided advantage over the other three for its endurance is much greater than the two steels without cobalt and it is not nearly as brittle as the low tungsten-cobalt type which has only slightly better average endurance at the highest cutting speeds.

The low-tungsten steels with or without cobalt additions are to be preferred when brittleness is unimportant and the tool can be well supported but severe oxidation is to be avoided. While the low tungsten-cobalt steel A requires a somewhat higher temperature than the steel C, which is cobalt-free, its endurance is somewhat greater. However, when the hardening temperature for the low tungsten-cobalt steel "A" is reduced to that recommended for the low tungsten-high vanadium steel "C" both have more nearly comparable endurance. This is indicated in Fig 1 and substantiated in tests contained in a previous report[15].

It is more difficult to point out decided advantages for any one of the four steels when maximum tool endurance and minimum oxidation and brittleness are all required. The choice, under such conditions, would depend upon the relative importance of, and quite probably be a compromise between the several factors considered.

There is evidently no one steel which meets all requirements of service for each has special advantages and disadvantages. The addition of cobalt to high-speed steels permits the use of higher hardening heats and so imparts a greater cutting capacity but does not change the characteristics of the two basic types, namely, low tungsten-high vanadium and high tungsten-low vanadium steels.

The endurance of high-speed steels subjected to the severe

(15) Refer to (1).

service described in the first two sets of tests was affected to a relatively small degree by variations in tempering subsequent to hardening. The frictional temperatures produced were not less than 1400 degrees Fahr. which is higher than that required to decompose the martensitic groundmass of the hardened steel. The degree of red hardness was therefore considered a function of the quantity and characteristics of the constituents formed at the high heats used in hardening (2200 to 2500 degrees Fahr.), as indicated by thermal analysis, and largely independent of the properties of the groundmass.

If this is so the question naturally arises why tools which will cut under frictional temperatures of 1400 degrees Fahr. would be entirely ruined if first tempered at this same temperature. While no final answer can be given, there are a number of important differences between tempering a tool and subjecting it to service at such high temperatures. In the first place the ordinary method of tempering consists in exposing the hardened steel to this temperature for a longer time than any of the tools would cut. Also it is well known that pressure as well as temperature markedly affects many atomic or molecular reactions. Temperature alone is applied to the steel in tempering whereas in cutting metals both high temperature and pressure are obtained. It is therefore conceivable that the pressure tends to retard the reactions which would take place at a given temperature and so tend to prevent complete reversal of the changes produced in the hardening or at least make them take place so slowly that the tools will cut for a definite length of time at such high heats before failure occurs.

The principal conclusions to be drawn from the described tests may be summarized as follows:

(1) The endurance of high-speed steels is affected to a marked degree by the high heat temperature used in hardening and rises rapidly with increase above 2200 degrees Fahr. However, a point is finally reached where a further temperature rise is no longer attended by a commensurate increase in the endurance and if high enough heats are employed a decrease will be observed coincident with a partial melting of the steel. Under otherwise fixed conditions there is therefore a high heat temperature which results in maximum endurance but this varies with composition. It is higher in the 18 per cent tungsten than in the 13 per cent

tungsten steels and is raised in both types by the addition of 3 to 5 per cent cobalt.

(2) The best hardening temperatures for the four main types of high-speed steel, to be used as lathe tools under severe service, are considered to be about as follows:

2350 degrees Fahr. for low tungsten-high vanadium steel
2400 degrees Fahr. for high tungsten-low vanadium and low tungsten-cobalt steels
2450 degrees Fahr. for high tungsten-cobalt steel

These temperatures are a compromise between several factors including tool endurance and brittleness.

(3) The endurance of high-speed steels is likewise dependent upon and, within limits, increases with the time at high heat. In tests made with high tungsten-low vanadium steel, tools held 3 minutes at 2280 degrees Fahr. had superior endurance to those held 50 seconds at 2400 degrees Fahr. but were not as good as those subjected to the latter temperature for 1½ minutes. Therefore for consistent results both time and temperature should be controlled by suitable instruments.

(4) High-speed steels subjected to the severe service described were found to have endurance characteristic of the high temperature treatment used in hardening and this was not modified to any great degree by any subsequent tempering up to and including 1100 degrees Fahr. However, the higher the tempering temperatures the tougher did the steel become. Thus the most important reason for tempering, in this case, is not increased endurance but decrease in brittleness.

(5) Length shrinkage or expansion may be produced in hardening a high-speed steel from a given temperature, if this is not too high, by varying the treatment prior to hardening. This includes both preliminary annealing and the manner of heating for hardening. However, the higher the quenching temperature and the time at high heat, within limits ordinarily encountered in commercial heat treatment, the greater will be the expansion or, under certain conditions, the less will be the shrinkage. Likewise tempering subsequent to hardening may be used to reduce original length shrinkage or expansion but the final length will approximate the original only in certain cases. The tempering which will produce this ideal condition will vary widely in a given steel de-

pending upon the previous history of the samples but in no case is it possible to completely compensate for hardening changes in two dimensions.

(6) In a series of tests on nickel steel forgings in which the cutting speed was varied from about 45 to 70 feet per minute, high-speed steels containing about 3.5 per cent cobalt had much greater endurance than the plain chromium-tungsten-vanadium steels. Under the most severe service the low tungsten-cobalt type was superior to the high tungsten-cobalt steel but at the lowest speeds both had comparable endurance. Comparisons of the four steels tested when based on the breakdown test, showed the following average order of superiority:

	Per Cent
Low tungsten-cobalt steel	98
High tungsten-cobalt steel	90
Low tungsten-high vanadium steel	68
High tungsten-low vanadium steel	47

(7) Low-tungsten steels, with or without cobalt additions are more sensitive to heat treatment than the high-tungsten types. They are more brittle when hardened for maximum endurance but require lower hardening temperatures than do the corresponding high-tungsten steels. These features, in addition to comparisons of endurance, must be considered in selecting steels for particular service. No one type of high-speed steel meets all requirements but each has its advantages and disadvantages.

(8) Both the "Breakdown" and "Taylor" tests have limitations and cannot wholly replace the method of using tools in the shop to determine just what they will do. However, much worthwhile information of practical value can be obtained in relatively short time by careful interpretation and correct application of results obtained by either test.

(9) In normal shop practice so-called "flaky" steel may be produced through the hardening of long lengths of lathe, planer and shaper tools followed by dressing operations in which only part of the previously hardened steel is heated to annealing temperatures which would ordinarily prevent its occurrence. As "flaked" steel is brittle and showed a tendency toward erratic results in lathe tests its production is to be avoided.

(10) Prevention of "flaky" fractures in ordinary high-speed

steel in heat treatment is much more simple than elimination and may be accomplished by annealing between successive hardening treatments. In no case, when once produced, was complete elimination effected by annealing alone though certain complicated treatments left mere traces of this structure upon rehardening. However, combined forging and annealing completely removed severe "flake" in all steels tested. In general the greater the reduction in forging the lower was the annealing temperature required for a cure (within limits).

(11) High tungsten-low vanadium steels offered the greatest resistance to the formation of "flake" and likewise to its elimination when once produced.

Acknowledgment is made to Miss I. J. Wymore, assistant chemist and H. C. Cross, laboratory aid, Bureau of Standards for taking the thermal curves contained in this report; to T. H. Johrden, machinist inspector, U. S. Naval Gun Factory for assisting in all the lathe tests and to J. W. Talley and T. Hamill, respectively assistant chemist, U. S. Naval Gun Factory and laboratory aid at the Bureau of Standards for assistance rendered in connection with the heat treatment of samples.

ACTIVITY OF SUB-COMMITTEE—I, ON RECOMMENDED PRACTICE FOR TREATMENT OF TOOL STEEL DURING 1922-23

THE selection of the members of this committee from the Pittsburgh district (which took place the latter part of October, 1922) was a propitious act by our president, as it is probable that in no other community could a combination of repre-

W. J. MERTEN
Chairman—Sub-committee—I, on the Treatment of Tool Steel

sentatives of tool steel users and manufacturers be found concentrated in so limited an area as within the boundary line of the Pittsburgh chapter of the A. S. S. T.

The committee is composed of four users and three manufacturers of tool steels, as follows:

User	Manufacturer
M. E. McDonnell	J. A. Succop
C. I. Neidringhaus	F. Garratt
W. H Phillips	J. Trautman
W. J. Merten, Chairman	

One of the manufacturers' representatives—a manufacturer of die blocks—is also partly a user.

The overbalancing position of the users—four to three—was immediately recognized as a decided advantage since the final treatment of these classes of steels rests principally with the users.

The committee held their meeting in the Old Colony club quarters in the William Penn hotel, Pittsburgh, Pa. At the first meeting it was decided that the committee devote its entire effort on the treatment of carbon tool steel, and if the time permitted, one grade of high-speed steel—the 18 per cent tungsten steel—in their program for the ensuing year.

After three sessions a tentative draft of these specifications for recommended practice was presented to the Standards committee at their New York session on March 5, 1923.

Revisions and additions, per the recommendation of the Standards committee were discussed and acted upon at meetings held during March, April, May and June. The following revised and complete recommended Process Specifications for the heat treatment of carbon tool steels and 18 per cent tungsten high-speed tool steels, were submitted to the Standards committee at their second meeting held in Bethlehem June 13, 1923. The records, minutes, transactions and recommendations of this session are reported in the succeeding pages.

It is felt that the work of the committee has been entirely successful in establishing a foundation upon which to build the entire structure of the practice of heat treatment of tool steels.

RECOMMENDED PRACTICE IN THE HEAT TREATMENT OF PLAIN CARBON TOOL STEEL

This is a tentative—RECOMMENDED PRACTICE—approved by the Standards Committee of the A. S. S. T. and will remain tentative until such time as it is adopted through letter ballot of the membership of the Society.

GENERAL—

This specification covers the process to be followed in the heat treating of plain carbon tool steel.

Part I

Normalizing of Tool Steel Before Hardening

PROCESS—

Operations:

Heating.

Cooling.

Heating: Place steel into furnace so as to expose maximum surface area. Heat uniformly to a temperature above the upper

critical point indicated in Table I below and hold at this temperature for sufficient time to obtain complete penetration of heat and refinement of grain.

Cooling: Remove from furnace and cool freely in air.

Table I

Normalizing

Carbon Range and Normalizing Temperature

Carbon	Degrees Fahrenheit	Degrees Centigrade
0.65 to 0.80 per cent	1475–1525	800–830
0.80 to 0.95 per cent	1475–1500	800–815
0.95 to 1.10 per cent	1500–1575	815–860
1.10 to 1.25 per cent	1575–1650	860–900

Cross Sections, Weight and Time

Thickness of Largest Section of Unit	Weight of Unit in Pounds (Approximate)	Approximate time of heating. In hours.	Approximate time of soaking. In hours.
Up to and including 1 inch	Up to 100	¾	½
Over 1 inch and including 2 inches	Over 100 and including 300	1¼	½
Over 2 inches and including 3 inches	Over 300 and including 500	1¾	¾
Over 3 inches and including 4 inches	Over 500 and including 1000	2¼	1
Over 4 inches and including 5 inches	Over 1000 and including 1500	2¾	1
Over 5 inches and including 8 inches	Over 1500 and including 2000	3½	1½

Part II

Heat Treating of Plain Carbon Tool Steel

PROCESS—

Operations:

Heating for quenching.

Quenching.

Tempering or drawings.

Heating: Heat the steel uniformly to the temperature indicated in Table II.

Quenching: Quench from this temperature in water but do not cool below temperature of boiling water (212 degrees Fahr.).

Table II

Heat Treating

Carbon Range, Per cent	0.65–0.80	0.81–0.95	0.96–1.10	1.11–1.25
Hardening Temperature	1550–1450 Degrees Fahrenheit	1460–1410 Degrees Fahrenheit	1390–1430 Degrees Fahrenheit	1380–1420 Degrees Fahrenheit
Quenching Medium and its temperature	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit

Tempering or Drawing: Reheat immediately in oil or salt ($NaNO_3$) or furnace for the time and at the temperature specified in Table III and cool.

Table III

Tempering or Drawing Tool Steel

Results Desired	Tempering Medium	Temperature
Relieving Strains	Oil	350 to 375 Degrees Fahrenheit
Strain Relieving and Reduction of Brittleness	Oil	400 to 500 Degrees Fahrenheit
To relieve strains and Toughen	Oil	500 to 600 Degrees Fahrenheit

Notes About the Process

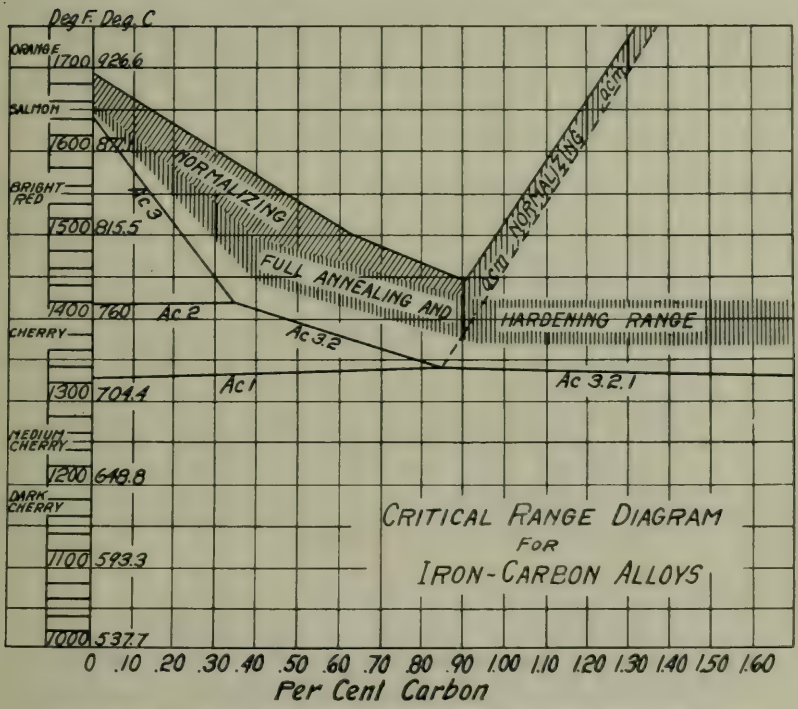
(a) GENERAL—

The recommended practice for the heat treatment of tool steel applies to highest quality performance of tools for general purposes only. For specific applications where special structural requirements seem to be necessary, deviation from the recommended practice must be left to the judgment of the individual heat treater or metallurgist.

(b) NORMALIZING—

A normalizing treatment for all tool steels is recommended to obtain a uniform and refined grain structure, which enables the operator to predict the behavior and performance of the steel tool during heating and quenching for hardening.

The variation in temperature for the different carbon ranges becomes evident upon a careful examination of



Critical Range Diagram for Iron-Carbon Alloys, Showing Normalizing, Annealing and Hardening Ranges.

the critical range diagram. A temperature very much in excess of that required to produce solid solution (austenite) is conducive of austenitic grain growth and intergranular weakness.

A low normalizing temperature for high-carbon steels (1.25-1.50 per cent carbon) which fails to break up the

massive cementite, results in a brittle structure, since the rate of diffusion of the excess cementite depends upon the temperature. The solubility of carbide in iron being greater or increases as the temperature rises, the rate of this solubility is equivalent to the slope of the Acm. line in the diagram.

The higher nomalizing temperatures given in Table I apply to the lower carbon ranges and the lower temperature to the higher carbon ranges for steel of the hypo-eutectoid composition, or in other words, "the normalizing temperatures for hypo-eutectoid steels varies indirectly as the carbon percentage rises or falls; and the normalizing temperature of hyper-eutectoid steels varies directly with the percentage of carbon."

(c) Heating for Quenching—

(a) The wide range of temperature in the 0.65 to 0.80 per cent carbon steel is needed, as a number of tools such as shear blades, arbors, mandrels, and others, are all around the low point, and because of mass and forms, require somewhat higher temperatures for quenching.

(b) The quenching temperatures given are at the lowest temperature range, consistent with highest quality of tools; deviations from it are not recommended, but may be practical for diverse reasons.

Quenching—

Water is the universal quenching medium and by varying its temperature and manner of application for the abstraction of heat, almost any degree of variation of structural conditions of the tool steel can be obtained. There are, however, special cases where oil may be a more suitable quenching medium.

Carbon Steels Suitable for Various Uses

Application

Carbon Content 0.65 *to* 0.85 *Per Cent*

Shear blades, boiler snaps and cups, hammers, stamping and pressing dies, mining drills.

Carbon Content 0.81 *to* 0.95 *Per Cent*

Hot and cold sets, chisels, dies, shear blades, mining drills, smiths tools, set hammers, swages, flatteners.

Carbon Content 0.96 *to* 1.10 *Per Cent*

Small cold chisels, hot sets, small shear blades, large pinchers, large taps, granite drills, trimming dies, turning tools, planer tools, drills, cutters, slotting and milling tools, mill picks, circular cutters, small shear blades, threading dies.

Carbon Content 1.11 *to* 1.25 *Per Cent*

Small cutters, small taps, drills, slotting and planing tools, wood cutting tools, turning tools, razors, etc.

Suitable Tempering Heats for Various Tools

Temperature—350 *to* 390 *Degrees Fahr.*

Lathe tools for brass and copper alloys. Milling cutters for brass and copper alloys. Scraper and cutting tools for soft metals and micarta. Drawing mandrels, drawing dies, bone cutting tools, hammer-faces, steel engraving tools, wood-carving tools, cutting tools for iron and steel, hand tools, threading dies for brass.

Temperature—400 *to* 500 *Degrees Fahr.*

Hand taps and dies, hand reamers, drills, bits, cutting dies, penknives, milling cutters, chasers, inserted sawteeth, press dies for sheet steel, rock drills, taps and dies, wire drawing dies, dental and surgical instruments, twist drills.

Temperature 500 *to* 600 *Degrees Fahr.*

Bending and forming dies, shear blades, chuck jaws, forging dies, drifts, gages, press-dies, flat drills, reamers, chisels and tools for woodcutting, hammers and drop dies, axes, lathe tools for copper augers, cold chisels, coppersmith tools, grinders, screw

drivers, molding and planing tools, hacksaws, needles, butcher knives, saws and tools.

RECOMMENDED PRACTICE IN THE HEAT TREATMENT OF 18 PER CENT TUNGSTEN HIGH-SPEED STEEL

This is a tentative—RECOMMENDED PRACTICE—approved by the Standards Committee of the A. S. S. T. and will remain tentative until such time as it is adopted through letter ballot of the membership of the Society.

GENERAL—

This specification covers the process to be followed in heat treating high-speed steel.

PROCESS—

Operations:

(1) Heating for normalizing (or annealing).
(2) Cooling.
(3) Heating for hardening—(a) Preheating—(b) Heating for quenching.
(4) Quenching.
(5) Drawing for secondary hardness.

(1) *Heating for normalizing*:

Heat slowly and uniformly to a temperature of 1600 degrees Fahr. (871 degrees Cent.) and hold for complete refinement.

(2) *Cooling*:

Cool in furnace, infusorial earth, mica, lime or any medium that will permit of uniform slow cooling.

(3) *Heating for Hardening*:

(a) Preheating—Heat slowly and uniformly to 1500 degrees Fahr. (816 degrees Cent.) in a furnace of sufficient size.

(b) Heating for Quenching—Transfer preheated steel to a high temperature furnace that is maintained at a temperature of 2250 degrees Fahr. (1232 degrees Cent.) to 2400 degrees Fahr. (1315 degrees Cent.), depending on the type of tools being hardened.

In order to obtain the most satisfactory "red hardness" conditions, the steel should be brought rapidly to the

higher temperature, but in many cases the character of the cutting edges of certain form tools, such as milling cutters, threading tools, etc., makes it inadvisable to use the higher temperatures owing to destruction of the delicate edges through blistering, pitting, etc. It is, therefore, usual to use the higher temperatures for tools such as rough lathe tools, while the finer class of tools is hardened at the lower temperatures.

High-speed steel tools should not be held at the high heat longer than necessary, since holding at the high hardening temperatures required causes excessive grain growth, with subsequent brittleness of the hardened tools.

Tools that cannot be ground after hardening, are often heated in a barium chloride, or some such suitable bath.

(4) *Quenching*:

Quench the steel in oil, or air, from the hardening temperature. It is advisable to maintain the oil quenching bath at a temperature of 150-200 degrees Fahr. (65-93 degrees Cent.) to eliminate possibility of breakage with intricately shaped tools.

(5) *Drawing for Secondary Hardness:*

Reheat uniformly in an open furnace, or preferably in a salt ($NaNO_3$) or lead bath, to 1050-1150 degrees Fahr. (565-631 degrees Cent.) for a sufficient length of time, and cool in air or oil as preferred.

Notes About the Process

Cooling From Normalizing—

Cooling in air should not be permitted, since air cooling from the normalizing temperature is apt to result in partial hardening of the tool.

Heating For Hardening—

It is the customary practice to always preheat for hardening in an open furnace, since preheating in a

salt bath causes the salt to adhere to the tool, and the subsequent high temperature treatment causes unusual corroding from the adhering salt. Even preheating in lead is objectionable from small quantities of adhering lead. There is not much advantage to be gained in using a molten bath for the preheating, since the preheating temperature may vary over the comparatively wide range of 1400 to 1600 degrees Fahr., and an open furnace is invariably used in practice.

Quenching from Drawing Temperatures—

This should be optional with the steel treater, as quenching from the drawing temperature does not give increased toughness over samples that have air cooled. Evidently the increased toughness resulting when carbon or chrome-vanadium steels are quenched from drawing temperatures of 700 to 1000 degrees Fahr. does not apply to high-speed steels, as impact tests on oil cooled and air-cooled samples show no difference in favor of the oil-cooled pieces.

ACTIVITIES OF SUB-COMMITTEE—IV, PYROMETRY, DURING 1922-23

SUBCOMMITTEE IV, Pyrometry, was organized for the purpose of developing in practical form useful information concerning pyrometers, to be presented to the members of the A. S. S. T. in "data sheet" form, subject, of course to their approval.

The procedure was an evolutionary development of the work accomplished by the standards committee of the previous year.

J. H. G. WILLIAMS
Chairman Sub-Committee IV, on Pyrometry.

Although that committee presented no definite report at the last convention, nevertheless it devoted much time and effort to the subject of pyrometers. It was felt by that committee that there was a demand in the metal treating industry at large, for practical information pertaining to the fundamental principles of pyrometers, their construction, their care, and their proper use.

The subject, however, did not lend itself to standardization as standardization is ordinarily interpreted. Gradually the idea developed that the demand could best be answered by the publication of brief, concise facts, in clear everyday language and that this information could be obtained most advantageously from men

thoroughly acquainted with all phases of pyrometer manufacture and practice.

To facilitate the holding of meetings, the selection of the various members was made with reference to Philadelphia as a geographical center.

The personnel of subcommittee IV, as appointed by President Lynch is as follows:

J. H. G. Williams, Billings and Spencer Co., Hartford, Conn. (Chairman).
J. J. Crowe, Met., Philadelphia Navy Yard, Philadelphia, Pa.
W. H. Laury, Bethlehem Steel Co., Bethlehem, Pa.
J. E. Halbing, Willys-Morrow Co., Elmira, N. Y.
C. H. Wilson, Pres., Wilson-Maeulen Co., New York City.
Morris E. Leeds, Pres., Leeds & Northrup Co., Philadelphia, Pa.
R. P. Brown, Pres., Brown Instrument Co., Philadelphia, Pa.
C. O. Fairchild, Physicist, Bureau of Standards, Washington, D. C.

At the first meeting of the subcommittee IV, very careful consideration was given to the ideas of the standards committee, and it was agreed that their plans represented the best crystalized expression of the policy to pursue in the handling of such an intractable subject for standardization.

Briefly, the method employed in developing the subject, was to hold a free discussion in which a careful record was made of all the ideas expressed; then to compile these ideas in logical form, sending copies to each member for written criticism. In this matter a composite expression of every man on the committee is incorporated in the final report.

Following this outline the report has been digested, and filtered three times. It has been approved by the subcommittee, approved by the standards committee, and is now submitted to the society as a whole for their verdict. It is submitted in the belief that it expresses useful and incontrovertible facts, stated in such a manner that any man able to read thoughtfully, can obtain a definite idea of the principles upon which the pyrometer is based, without being confused by technical terms; also a working knowledge of the construction of pyrometers, and finally, definite instructions as to their proper use.

The society is indebted to the members of this subcommittee

for their unselfish expenditure of time, and broad attitude in expressing the subject without tint of commercialism.

The chairman wishes to thank the members of the subcommittee, and their representatives for their patience, friendly cooperation, and deep interest.

Furthermore, he desires to call to the attention of the society that the drudgery of sifting the data, compiling and rewriting it, many times, until it was approved by all members of the subcommittee was performed by C. O. Fairchild, of the U. S. Bureau of Standards. It is due to his steady work, and discriminating judgment, that the society has obtained an exposition of literary, as well as scientific merit.

The following is the table of contents of subcommitte IV report:

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PYROMETRY

Notes on Thermoelectric Pyrometers and Instructions for Their Use in Heat Treating Steel

Preface

PYROMETRY, or the art of measuring high temperatures is a vital factor in the continued supremacy of American metal industries. American methods of quantity production and interchangeability of parts demand uniformity in the quality of products. Uniformity is maintained by the careful control of processes and materials, and the use of precise instruments such as pyrometers, micrometers, gages, and recording instruments.

In the last twenty years pyrometry has been developed in practical uses until today, the pyrometer, especially of the thermoelectric type, is a practical device of tested and proven worth. It may be used without complete knowledge of the principles of its action, but as in the use of any instrument some information about it is necessary, and this treatise has been prepared to furnish such facts and advice as will enable a heat treater to use a pyrometer to the best advantage.

Introduction

Before discussing methods of measuring temperature, and the use of such measurements to control a furnace, it is necessary to have a very clear idea of what "temperature" means, what "heat" means and how they are connected.

The idea of "temperaure" is simple. We know when a piece of steel is hot or cold and that the hot piece is at a higher temperature. "Heat" is our expression for the energy in the steel, which makes it hot. Roughly speaking the quantity of heat in the piece of steel is proportional to the temperature. This heat may come out—by conduction or radiation. Radiating heat tells us that a substance is hot even when it is not red hot. We can feel the heat radiated. Sometimes a furnace is said to be at a "red heat" or "white heat." These are good and very useful terms, but avoid the expression "degrees of heat." Temperature is measured in degrees, and heat in British thermal units, (B.t.u.), or calories, or

watts. Become accustomed to the use of "temperature." It will be easier if you are using pyrometers and know what the temperature is—in degrees.

How is temperature measured? Temperature is not a quantity with dimensions such as length, or weight, or time, and two temperatures cannot be added like two yards, or two seconds. But heat is energy and affects all substances in some definite way. For example, a rod of metal, say copper, expands when heated. It

The First Form of Pyrometer

always expands the same amount when a certain quantity of heat is put into it. Moreover, this quantity of heat always raises the rod to the same temperature. So, here we have a means of measuring temperature. This principle is used in certain types of thermometers. Other effects of heat are used, and one of the most peculiar and interesting effects is used in the thermoelectric pyrometer, which is an instrument for measuring high temperature.

I. Thermoelectric Pyrometer

In this pyrometer heat is made to develop electricity which in turn is conducted to an electric meter or indicator. It is easily

seen that the electrical effect of heat must be carefully controlled so that it will be a correct indication of temperature. Pyrometer manufacturers have learned through long experience how to do this successfully.

Just 102 years ago it was discovered that if two wires of different metals be joined, at one end, and this end be put into a furnace, or we may say immersed in the heat, and the cold ends outside be connected to a sensitive voltmeter or ammeter, the meter will show that an electric force is causing a current to flow in the metallic circuit. The electrical circuit is shown in Fig. 1. The two wires in the furnace are called a thermocouple. The thermocouple is usually connected by a pair of flexible leads to the

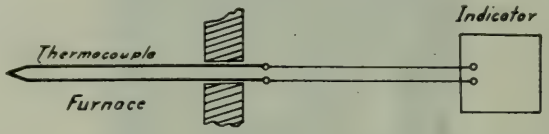

Fig. 1—Diagram of Simple Thermoelectric Circuit with Thermocouple in Furnace. There are Three Junctions in this Circuit. One Cold Junction is at Indicator, the Second just outside of the Furnace and the Hot Junction at the tip of the Thermocuple in the Furnace.

meter or indicator which is kept away from the furnace. Many years later it was discovered that if this circuit is made right, the electromotive force or for short "e.m.f." will depend only on the temperature of the hot junction in the furnace, and its value will correctly indicate the temperature. Unfortunately there are three points in this simple thermoelectric circuit at which an e.m.f. exists. These are the hot junction and the two cold junctions connected to the meter. These e.m.fs. depend on the temperatures of the junctions. Their sum is the total e.m.f. acting on the meter. Obviously we *must* take care of the temperature of the cold junctions (as described in sections IIIb or V) or else the total e.m.f. will not depend alone on the temperature of the hot junction.

II. Thermocouple or "Fire-End"

a. Metals Used.

Very few metals and alloys are suitable for thermocouples. They must have the following properties as far as possible.

1. Be refractory, that is, resist the actions of heat such as

melting, oxidation, crystallization, and general contamination with foreign substances.

2. Give a large e.m.f. The largest e.m.f. given by any thermocouple is barely over 50 millivolts or 50/1000 of a volt.
3. Be cheap—considering the length of service. The metals used for thermocouples at the present time are:
   1. Platinum
   2. Platinum alloyed with rhodium
   4. Nickel—chromium alloys
   3. Nickel
   5. Iron
   6. Iron-nickel-chromium alloys
   7. Nickel-aluminum alloy
   8. Nickel-copper alloys
   9. Copper
   10. Occasionally silver, gold, palladium, iridium, cobalt, manganese. Also alloys of these metals.

Some of these alloys have trade names such as "chromel" for No. 4, "nichrome" for No. 6, "alumel", "constantan", "ideal", "advance", "copel," and others for No. 8. Thermocouples made of platinum and rhodium are sometimes called "rare metal" or "noble metal" thermocouples. Others are called "base metal" thermocouples. In the following table we have arranged some of these metals and alloys in a thermoelectric series, in which the e.m.f. between two elements will be larger the more separated in the series.

1. Chromel
2. Nichrome
3. Iron
4. Copper
5. Pt 87%, Rh 13%
6. Pt 90%, Rh 10%
7. Platinum
8. Alumel
9. Nickel
10. Constantan
11. Copel

For example chromel or nichrome combined with constantan or copel give a comparatively large e.m.f. while nickel versus con-

stantan, or platinum-rhodium versus platinum give a rather small e.m.f.

The more common combinations, with the maximum temperature they should be used are:

1. Rare-metal (platinum, platinum-rhodium) to 2600°F (1427°C)
2. Chromel-alumel to 2000°F. (1093°C)
3. Iron-constantan or nichrome-constantan to 1650°F.
4. Copper-constantan to 800°F. (437°C)

Short exposure to somewhat higher temperatures will not ruin the thermocouple, but will shorten the life, and may cause it to indicate the wrong temperatures afterwards.

b. Protection Tubes.

In order to protect the elements of the thermocouple as much as possible from the effects of contamination and oxidation by furnace gases and vapors, they are mounted in closed-end tubes of metal or porcelain or other refractory and preferably gas-tight material. The tubes and fittings also protect the couple from breakage or similar injury. The choice of a proper protection tube is just as important as the selection of a thermocouple. The tubes must be

1. As gas-tight as possible.
2. Resistant to high temperatures.
3. Resistant to sudden changes of temperature (These may crack porcelain).
4. Mechanically strong.
5. Resistant to corrosion by acid fumes or other active vapors if present.

The best protection tube for a rare-metal couple is porcelain glazed on the outside; or for temperatures not too high a vitrified porcelain may be used. Fused quartz may be used up to about 1900° Fahr., where it begins to crystallize and leak furnace gases rapidly besides getting weak.

The best protection tubes for chromel-alumel couples are made of chromel, nichrome, nickel, or for special purposes porcelain or quartz.

Iron-constantan couples are protected with nichrome, nickel, or iron.

Seamless soft steel tubes are sometimes used instead of wrought iron.

Calorized iron and other alloys are often used.

In selecting a protecting tube be sure it will be good company for the couple. For example, the chromel-alumel couple has very little iron alloyed with it. So do not put it in an iron tube if you want the best results. Put it in chromel, nichrome or nickel.

When conditions are particularly severe as at the higher temperatures which are used for high-speed tool steels, double protection is necessary to keep the thermocouple in good condition. Outer tubes generally called secondary protection tubes are made of iron, chromel, carborundum or fire clay. The pyrometer manufacturer can be depended on to provide the best kind of protection for a thermocouple.

c. Insulators.

Within the protection tube the wires or elements of the couple are kept apart and electrically insulated (except at the welded hot junction) with porcelain, fireclay, asbestos, or glass insulators. Fireclay insulators are the best for base metal couples, but asbestos is good enough up to 1100 or 1200° Fahr. Only a very pure fireclay, or else porcelain should be used for rare-metal couples.

d. Terminal Heads.

The end of the mounted thermocouple outside the furnace is provided with a terminal head which keeps the inside of the tube clean, supports insulated terminals or binding posts for the thermocouple and leads, and may be threaded to fit a metal housing or pipe-line.

The best terminal heads protect the binding posts from dirt and weather, and are usually made of metal and asbestos board.

III. Leads from Thermocouple to Indicator or Recorder

The leads from the thermocouple have been made in the past simply of copper but at present they are more generally selected for a special purpose (see below) and are called

a. Extension Leads (Not copper).

Extension leads are made of special alloys which can be drawn to small wires and stranded. The purpose of the extension lead is to counteract the cold-junction e.m.f. at the terminal head and set up an e.m.f. at some other point away from the furnace,

where the temperature is constant and in the neighborhood of ordinary room temperature or 75° Fahr. It is not necessary to keep the cold junction at 75° Fahr. but it is necessary or at least highly preferable to keep it constant and *know what it is.*

b. Cold Junctions.

There are a few standard methods of handling the cold junction and four of these are shown in Figs. 2, 3, and 4. In Fig. 2 is the simplest arrangement, in which the cold junction is at the

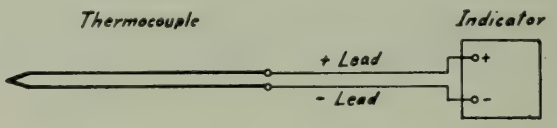

Fig. 2—Diagram of Thermoelectric Circuit in which the Cold Junction is at the Indicator.

indicator. In Fig. 3, is another convenient arrangement in which the cold junction is buried in the ground. Fig. 3A is a modification of Fig 3.

The interesting part of this circuit, Fig. 3, is the connection of two positive leads to the indicator. The positive lead from the cold junction is connected to the negative terminal of the indicator. It will be necessary to consider carefully the e.m.fs in this circuit Let us start at the hot junction, and follow the arrow.

Hot-Junction E.m.f		Indicator-Terminal E.m.fs.		Cold-Junction E.m.fs.
Constantan to iron	→	+to brass and brass to +	→	+ to —

and back to the hot junction. At the indicator two e.m.fs are equal and opposite if the two terminals of the indicator are at the same temperature. Hot drafts from a furnace may heat one terminal more than the other. Another interesting fact is that the cold-junction e.m.f in this circuit is equal to the difference of the two cold-junction e.m.fs in Fig. 2, at a certain temperature, say 75° Fahr. in each case. The best feature of the circuit of Fig. 3, is its adaptability to the scheme shown in Fig. 4, in which one cold junction is used for any number of hot junctions. In this figure the cold-junction leads are connected between the in-

dicator and a commutating switch. This switch is made so that no extra e.m.f.s are set up to cause trouble. In all cases like the diagrams in Fig. 3 and 4, the extension lead from the cold junction to the indicator is connected to the indicator terminal of opposite sign to the lead. Plus and minus leads when new are al-

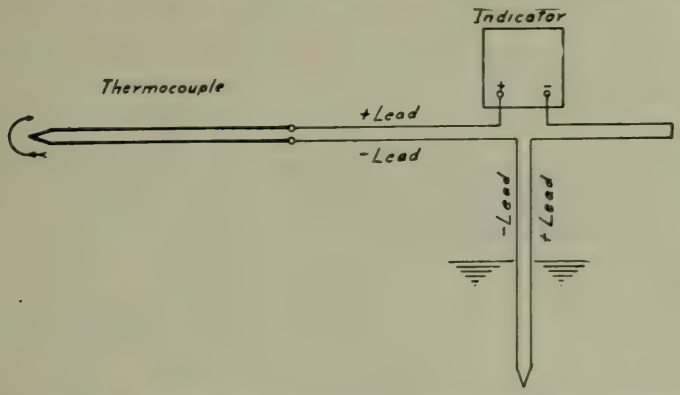

Fig. 3.—Diagram of Thermoelectric Circuit having Two Positive Leads to the Indicator.

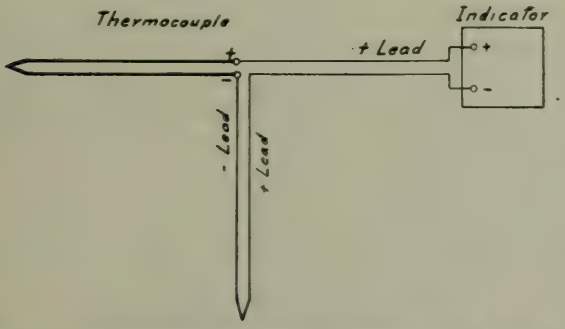

Fig. 3A—Diagram of Thermoelectric Circuit having Two Positive Leads to the Indicator. This is a Modification of Diagram in Fig. 3.

ways distinguishable by marks at their ends, or by the color of the insulation. In any case the manufacturer provides some means of identifying the leads and will furnish instructions for wiring according to his particular method.

Burying the cold junction in the ground is one way to take care of it. The junction should be at least ten feet down and safe

from moisture and the heat from hot pipes or flues. A good method is illustrated in Fig. 5. A 2-inch pipe forged sharp and capped is driven into the ground and nearly filled with heavy oil. A 3/4-inch pipe within this and fitted at the top contains the wires. It is better to install at least two pairs of extension leads. The cold junctions are hard soldered or welded (using borax) and wrapped

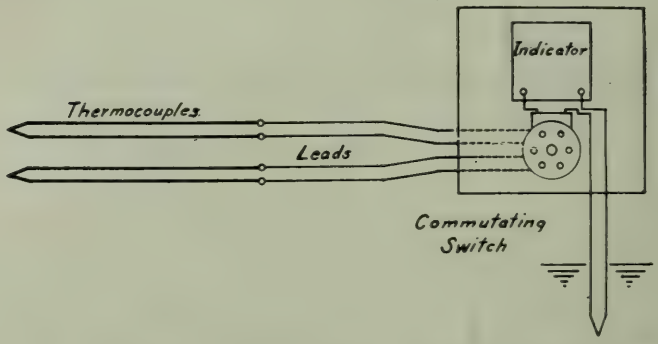

Fig. 4—Diagram of Thermoelectric Circuits Using One Cold Junction for any number of Hot Junctions.

with tape. One pair of the leads is used to measure the temperature of the bottom of the hole. We will leave it to the reader as to how, by aid of a thermometer at the terminals of an indicator, to measure the cold-junction temperature. This should be done from time to time and recorded, or used in making adjustments described in later paragraphs.

Methods for automatic compensation for variation in the temperature of the cold-junction are described in section V.

IV. Indicators and Recorders

a. Millivoltmeter Type.

1. Indicator.

A millivoltmeter is an instrument for measuring millivolts or "thousandths of a volt." The inner parts of an ordinary type are shown in Fig. 6. The main parts are (1) a permanent magnet, (2) a moving coil of fine copper wire mounted to turn between the poles of the magnet, (3) a light and long pointer (made of

fine aluminum tubing) attached to the moving coil, and (4) a scale to read the deflections or positions of the pointer and coil.

The permanent magnet has been heat treated in such a way that its magnetism or strength will stay constant for years, that is, it is permanent.

The moving coil is made very light, to swing easily, and mounted on steel points resting in jewelled bearings. Some manufacturers support the coil on only one pivot, and others support it

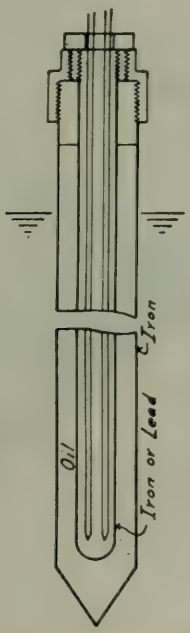

Fig. 5—Sketch Showing a Good Method for Maintaining a Constant Cold Junction.

by small metal strips or "suspensions." This coil is connected to the two terminals of the indicator.

In order to understand the use of a millivoltmeter, it is necessary to know how it works. The action is very much like that of a motor, only the moving part is kept from turning too far by coiled springs. An electric current forced around the electrical circuit by the e.m.f. or millivoltage of the thermocouple makes the coil turn. The amount of the current will depend on the e.m.f. of

the thermocouple and the electrical resistance of the circuit. So, strange to say, a millivoltmeter is really a milliammeter, and its indications or deflections of the pointer are proportional to the current. This is unfortunate, because it is the e.m.f. of the couple which we want to know, or else the temperature which controls the e.m.f. Now in order to use a millivoltmeter correctly, the resistance

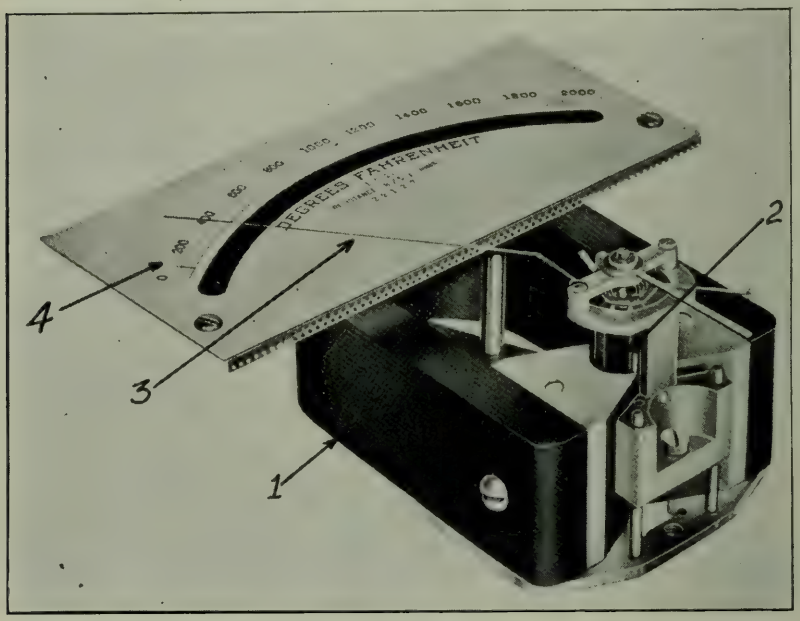

Fig. 6—Photograph of the Ordinary Type Millivoltmeter.

of the circuit (thermocouple, leads, and indicator) must be carefully adjusted. The maker of the pyrometer calibrates or tests the indicator for a fixed or definite resistance, for example, 100 ohms. Allowance may be made for a certain amount of resistance of the thermocouple and leads. An arrangement might be: 100 ohms in the indicator and 10 ohms in the outside or external circuit, making a total of 110 ohms. Suppose the couple or leads were injured and had 20 ohms instead of 10 ohms. Then the current in the circuit would be reduced almost 10 per cent, and the indicator would be 10 per cent "off", 10 per cent of 1000 degrees is 100 degrees, and an error of 100 degrees is intolerable. To prevent this, the pyrometer must be carefully installed and the con-

nections kept clean and tight. Even then small changes in the resistance will occur. For this reason the best indicators are made with a high resistance so that a small change in the resistance of the line or the thermocouple will not give an appreciable error.

Low-resistance indicators are on the market, and some of the older types have a resistance of only one or two ohms. These indicators seldom indicate correctly and usually are so far wrong that they do more harm than good.

It is difficult to recommend definitely the amount of resistance of the indicator which should be demanded. This will depend on the accuracy required, and the kind of installation. A resistance of less than 10 ohms should never be used. A resistance of 100 ohms may be considered satisfactory provided the plant conditions make it possible to install the pyrometer so that the circuit will not change by more than a small fraction of an ohm. A resistance of 200 ohms or higher is to be preferred. It cannot be made as high as desirable because the indicator would become too delicate for factory use.

The pointer and moving coil are the most delicate parts and are very easily injured if the case of the indicator is opened. Only an expert instrument maker is able to handle and adjust these parts. Sometimes the coil and pointer stick or catch on dirt or dust which has gotten into the case. If light tapping on the case does not loosen the moving parts, the instrument must be returned to the maker for cleaning. The force developed by the electric current (from the thermocouple) flowing through the moving coil is very small. In a high grade indicator the thermocouple is allowed to deliver about 1/10,000 watt or about one millionth of a horse-power. It does not take a very large piece of dirt to stop the coil and pointer and make them stick.

2. Recorder.

A recording pyrometer can be used to great advantage by heat treaters in hardening and tempering finished work, in "soaking" large parts, and in many other classes of work, in which the rate of heating must be controlled. It is a nuisance to control the rate of heating with an indicator, but it can be done by using a log sheet to write down readings regularly. The recorder does this automatically by momentarily pressing the pointer of the meter against

the record paper at regular intervals, while the paper is steadily moved along under the pointer. In this way the rate of rise or fall of the temperature of the furnace is shown as a curve on the paper. This rate of heating will not be very different from that of the piece of steel being treated, if the thermocouple in the furnace is very near or touching the piece.

The recorder is a continuously running machine, and so it must be carefully attended. It must be kept clean and in some cases oiled, and directions given by the pyrometer manufacturer must be followed. Whenever the paper chart is changed, or adjustments made, be sure to notice the position of the pointer, to see whether it is swinging free or caught tight under the pressor bar.

Many recorders are made to take care of more than one thermocouple. They are then called multiple or multiple point recorders, and have a commutating switch, that is, a switch for connecting each thermocouple in turn. There is nothing complicated about the electrical circuit. Each thermocouple is connected to the switch. The circuit for each thermocouple can be considered by itself, because the switch connects only one couple at a time, and disconnects all others.

Everything stated in the section on indicators applies for recorders. The resistance of the circuit and care of the cold junction must be considered. Usually the meters of recorders are lower in resistance and stronger in construction. The recorders are not moved about, and with well installed leads and thermocouples, they will record correctly. However, a resistance of 50 ohms or more is just as desirable as for indicators.

b. Potentiometer Type.

1. Indicator.

A potentiometer is an instrument for measuring e.m.f. (or, in pyrometry, millivoltage) without allowing any electric current to flow in the line and thermocouple.

The potentiometer does this by balancing or "bucking" the e.m.f. of the thermocouple with part of the e.m.f. of a small battery, usually a dry-cell.

Fig. 7 shows the wiring diagram or electrical circuit of a potentiometer connected to a thermocouple. Current from the battery flows through the resistance a,b,c. The e.m.f. of the battery

makes the point 'c' at a higher electrical potential than 'a'. This difference in potential is nearly the whole e.m.f. of the battery. At a point b, somewhere along the resistance the em.f. from 'b' to 'a' may exactly equal the e.m.f. of the thermocouple T. When this is true and the e.m.f. of the thermocouple "bucks" the e.m.f. along the resistance, the meter 'G' will show that no current is flowing in the thermocouple. When the e.m.f. of the couple changes, the point 'b' must be moved along the resistance to balance the e.m.f. The

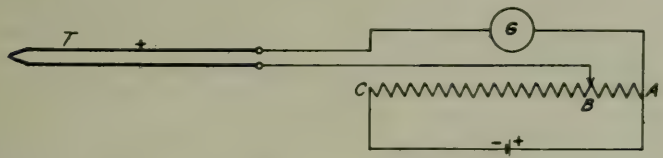

Fig. 7—Diagram of an Electrical Circuit of a Potentiometer Connected to a Thermocouple.

positions of 'b' are marked in millivolts or temperature, so that by balancing e.m.f.s, temperature can be measured.

The battery cannot be depended upon to keep a steady or standard current flowing in the circuit. So it is necessary to adjust the current. This is done by balancing the battery against a standard cell. The standard cell and battery are contained within the case of the instrument. The battery must be renewed when it is found that it will not furnish enough current.

The directions for operating a potentiometer are simple, but must be followed carefully.

The manufacturer furnishes directions with each instrument stating how to connect the thermocouple, obtain a balance against the standard cell, then against the thermocouple. After one balancing against the standard cell the current from the battery will stay constant for a few hours, and need not be readjusted for every reading.

The scale of the potentiometer can be made very long so that small differences or changes in temperature can be read. Besides this, readings of the instrument are not affected by changes in the resistance of the thermocouple and leads. On this account a portable potentiometer is very convenient for checking installed instruments.

2. Recorder.

Briefly, a potentiometer-recorder is a potentiometer with a mechanism for automatically performing the balancing of e.m.f.s (described above), and for printing or drawing a curve on the record paper. There are two general types. (1) Single-point or curve-drawing recorder. The pen of this recorder remains in contact with the paper and a full-line curve is drawn. The recorder does not, ordinarily, automatically adjust its standard current, and this must be done by hand. (2) Multiple-point recorder. This recorder is made for four or more thermocouples and prints the record by numbers corresponding to thermocouples. For example, a line of 4's shows the variation of temperature, instead of a line or a row of dots.

There is not space in this treatise to describe the mechanism of the potentiometer recorder. The user of the instrument should very carefully study the instructions supplied by the manufacturer. A working knowledge of the instrument is necessary, to get the greatest usefulness out of it.

Do not attempt to make adjustments nor arrange a special circuit without thoroughly studying the scheme, and sketching the circuits. The external circuits—that is, couples and leads are identical to those used with millivoltmeters, excepting the variable length or resistance of leads, which must be kept constant for the millivoltmeter-recorder.

V. Cold-Junction Compensation

When extension leads are used or when the thermocouple is directly connected to the instrument without any leads, the cold junctions may be at the terminals of the indicator or recorder. In this case, automatic cold-junction compensation can be used.

Automatic compensation needs no attention besides the precaution of placing the indicator (or recorder) where there are no sudden changes of temperature. The automatic device will not adjust itself to sudden changes of temperature of the cold junctions.

The simplest method of adjusting for the cold-junction temperature is by turning the pointer of the millivoltmeter (by means of the zero-adjuster) to read this temperature or equivalent e.m.f. on open circuit. This method is very satisfactory if the cold junction is buried or otherwise kept fairly constant.

The hand-adjusted compensator provided for potentiometer-

indicators or recorders is operated by simply turning a knob to read the temperature or e.m.f. of the cold junctions. It consists in a separate slide-wire resistance and a moving contact to add to the e.m.f. of the couple the cold-junction e.m.f.

VI. Installing Pyrometers

a. Thermocouple or Fire-end.

The thermocouple permanently installed should be mounted firmly in the furnace wall, with the hot end extending well into the furnace. For example, a fire-end with a protection tube 3/4 inches in diameter should extend into the furnace at least 8 inches. If less than this the end will not be as hot as the furnace. The couple must not be placed where flames will strike it, and the hole in the furnace wall must be filled or packed tight or covered by a flange, so that heat from the furnace will be kept from the terminal head, and cold air will not be sucked in upon the hot end.

In a heat treating furnace it is convenient to place the thermocouple so that the hot end can be seen through the door. If possible, it is a good plan to mount it so that the pieces of steel can be put against the protection tube. In this way the temperature of the couple and of the steel will be nearly the same.

If this is not done the furnace temperature must be uniform enough so that the temperature indicated by the pyrometer will be the temperature of the steel being treated.

b. Leads or Connecting Wires from Thermocouple to Indicator.

The best way to install leads is in iron conduit similar to ordinary electric wiring. The conduit should be kept cool and dry and must not be in electrical connection with lighting or power circuits. If the leads are not in conduits, mount them out of the way. When the cold junction is buried, place it near a wall or an upright post or girder of the building, so that the wires can be led to it conveniently.

If extension leads are used it is often necessary to use a certain length provided by the manufacturer of the pyrometer. The leads should be bought to reach exactly from fire-end to indicator.

c. Indicator.

The place to put an indicator is decided by where it will be easily seen, and at the same time, where it will be away from the heat, dust, and fumes around the furnace. Mount it firmly, on

a post or wall free from vibration or jar. If possible, have the service man of the manufacturer advise where to place the indicator or the recorder. The pyrometer manufacturers make special wall-type indicators, which can be bolted or screwed to the wall, the scale showing in front. The portable millivoltmeter or potentiometer used in a semi-permanent installation should be placed on a shelf or table, face up. If it is particularly necessary to stand a portable millivoltmeter to be read from a distance, be sure to adjust the pointer to read zero or the cold-junction temperature, with the meter in such a position.

d. Recorder.

A recorder requires more careful selection of a place to mount it. The necessity of opening the case to remove or replace the record paper, increases the possibility of getting dirt into the instrument. For this reason it is best to mount the recorder on a side wall, or near it, where it can be kept clean.

Special panels or instrument boards are sometimes advisable, especially when the heat treating room is very large, and furnaces are far from the walls. They are too expensive to use to mount a single indicator, but may be preferred for a recorder, or four or five indicators.

e. Connecting the Thermoelectric Circuit.

Connecting the circuit of thermocouple, leads and instrument is a "+ and — job." The terminals of the indicator are always marked, and likewise the terminals of the mounted thermocouple. Extension leads are either marked + and — or are distinguishable by the color of the insulation. If there is any doubt about the polarity of the leads connect them first to the indicator and short the other end by clamping or merely holding the ends together in contact. Warming this contract a few degrees should make the meter read plus. If it does not, reverse the connections at the meter. Now connect the thermocouple. If the extension leads are connected wrong, that is, if the plus lead connects the minus terminals of fire-end and indicator the result is double errors at both ends of the leads. The right ways to connect circuits are shown in Figs. 1 to 4, which give the common kinds of circuits usually employed.

VII. Checking the Pyrometer

a. The Thermocouple.

The deterioration of the thermocouple, that is, the change caused by oxidation of the wire, or contamination of it by vapors is unavoidable, and is more rapid the higher the temperature. The e.m.f. of the thermocouple almost always drops off with age, and the pyrometer reads too low. Months are required to cause large errors, unless very high temperatures are used. For example, a base-metal couple used at 2000° Fahr. ought to be checked about once a week.

A portable checking outfit is highly recommended. A good base-metal couple insulated with fireclay, without any protection tube, connected by a few feet of extension leads to a portable millivoltmeter or potentiometer are very satisfactory for checking temperatures not over 1800° Fahr. Above this, use a rare-metal thermocouple protected with a 1/2 inch glazed-porcelain tube.

The best way to check an installed fire-end is to put the checking thermocouple or standard into the furnace alongside it. It is very important to be sure that the furnace temperature is uniform enough so that both thermocouples are really at the same temperature. One good way to be sure about this, is to use an unprotected thermocouple and put it in the same protection tube with the installed one. Sometimes this cannot be done, and the next best way is to put the hot junction of the standard hard against the protection tube of the installed thermocouple, keeping the furnace at a steady temperature, near the temperature which is used most. If the installed fire-end gives a reading say 980 degrees when the standard indicates 1000 degrees, use a percentage correction, that is, 1000-980/1000 or 2 per cent., and not a flat 20 degree correction. It is better however to check at a temperature close to the one used most.

b. The Indicator.

The first thing to do is to see what the indicator reads on open circuit. If an indicator is graduated only in degrees of temperature, that is, if the scale only reads temperature and not e.m.f., the only simple way to be positive that it is all right, is to substitute another indicator of the same type. If the scale is a double one, and also shows e.m.f.—or only e.m.f—the indicator

can be checked by substituting a portable meter or potentiometer which indicates e.m.f. If the installed indicator reads too high return it to the maker. If it reads too low the resistance of the line may be too high, from bad contacts or partly broken leads. In this case the portable indicator will also read too low unless it is a potentiometer or a millivoltmeter which has a very high resistance—high enough to swamp out the resistance effects of the leads.

The commonest trouble with indicators is sticking of the moving coil and pointer. It is easy to learn if this is happening by watching the pointer move and by tapping the instrument with the knuckles or fingers. Occasionally the only cause of sticking is a loose scale which touches the pointer, or some paper fibre or dust sticking to the scale. When quite certain that this is not the cause of sticking the instrument may be returned to the maker for repairs.

c. The Leads.

Inspection of the leads and their connections should be made occasionally. If the leads are suspected of being the cause of an open circuit, connect the fire-end to the indicator with some copper wire, after disconnecting the installed extension leads. Each side (+ and —) of the leads can be tested separately. When both are off and the fire-end connected with copper wire only, the cold junctions are at the terminal head of the fire-end. This will require correction of the reading indicated with copper leads.

Do not allow the plant electrician to test the leads for breaks or grounds without disconnecting the indicator.

If a ground to the lighting or power circuit is suspected, the surest way to prove it is to find the main switch and throw off all high voltage circuits. If, by the change, a connection is shown between pyrometer and lighting circuit, carefully examine the entire pyrometer installation. The connection may be through metal at a furnace, along a wet wall, through wet ground (particularly to a buried cold junction), or through the conduit when wet inside.

When a final check on the pyrometer as a whole does not give a result which satisfies good judgment, consult with others and get in touch with the pyrometer manufacturer, the local A. S. S. T. or anyone known to be using pyrometers.

Before consulting others, it is wise to rehearse your trouble, and to be sure you can blame it on the pyrometer and not on some forgotten change in procedure or practice.

VIII. Important Points to Remember

A pyrometer indicates the temperature of the fire-end, and unless the furnace is uniformly heated, the indicated temperature will represent only the part of the furnace near the fire-end or thermocouple.

Have the thermocouple installed where the hot end of the protecting tube can be seen through the furnace door or through a peep-hole. Put the thermocouple as near the work as convenient. Suppose the steel is to be quenched from 1500° Fahr. Heat slowly and evenly until the pyrometer indicates 1500° Fahr. *To be sure the work is at the indicated temperature, look through the door and compare the brightness of the work and the fire-end.* Experience has shown that the temperature of the work can be very accurately adjusted to the temperature of the fire-end by this method; and with care this accuracy can be gotten to plus or minus 10° Fahr.

There is one precaution necessary in the above method. In some furnaces the flame strikes against a part of the wall and heats it to an extra high temperature. Light from this hot spot or from the bright flame may make the fire-end *or* the work appear hotter than they really are. To avoid this trouble change the furnace or the burner.

About the Cold Junctions.

Know what the cold junction temperature is, by measuring it with a thermometer, unless the pyrometer is equipped with an automatic cold-junction compensation device.

Extension leads do not compensate for cold-junction temperature. They only move the cold junction away from the furnace.

If the pyrometer is not corrected for the cold-junction temperature, it will indicate a wrong temperature of the furnace.

About Extension Leads.

Be sure the plus and minus wires are connected to the plus and minus terminals of the thermocouple, (fire-end).

Do not use extension leads intended for base-metal thermocouples, for rare-metal thermocouples, or vice versa.

Do not let extension leads get wet particularly those insulated with asbestos.

Extension leads have a high electrical resistance and should only be used in specified length supplied by the manufacturer, (unless the indicator or recorder is a potentiometer).

About the Thermocouple.

Different types of thermocouples will not indicate the same temperature unless they are connected to an indicator or recorder intended for them.

If the wires or elements of a thermocouple break they can be welded together again. In welding base-metal thermocouples use borax as a flux.

Use no flux on rare-metal wires.

An oxy-gas or oxy-hydrogen flame is required to weld a rare-metal thermocouple.

Throw away old base-metal thermocouples so that nobody can use them and get into trouble.

About Indicators and Recorders.

Indicators and recorders must be mounted where vibration and jar will not injure the delicate parts of the mechanism, and where they are not exposed to corrosive fumes, smoke or dirt, water, or excessive heat. They must not be mounted on a hot furnace wall, or where radiation or hot air from the open furnace door, or from the hot work removed from the furnace will heat them high enough to feel at all uncomfortably warm to the hand.

Do not open the case of a millivoltmeter. If the pointer sticks and cannot be loosened by tapping the case with the knuckles, return the indicator to the maker to be cleaned.

Do not let lighting or power circuits get crossed with the pyrometer circuit. A pyrometer will not stand more than one-tenth of one volt (0.1 volt) in its circuit.

When using a multiple point potentiometer recorder, always short the "points" not in use. Otherwise the instrument will drift on these points and confuse the record.

Potentiometer recorders are supplied with means for indicating when the battery cells are run down. Use only one dry cell in series (any number in parallel).

Any pyrometer will usually indicate wrong if *anything* about it is wrong.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 93. What are the more common methods of quenching ordinary taps? Are they quenched all over and the shanks drawn, or are they quenched only on the threaded portions; or are both the threaded portions and the tangs quenched, leaving the center portion of the shank soft?

QUESTION NO. 94. What are the most salient causes of the explosive disruption of many hardened steel articles?

QUESTION NO. 95. What is meant by "self hardening" steels?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 67. What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?

The answer to this question appearing in the June 1923 issue of TRANSACTIONS, has caused the following discussion.

DISCUSSION. By H. W. Lincoln, industrial heating engineer, Connecticut Light & Power Co., Waterbury, Conn.

The reason given that brine has a higher specific heat than

water would be a very logical explanation, but most authorities give brine a lower specific heat varying from 0.99 per cent for a one per cent solution to 0.78 per cent for a 25 per cent solution. Furthermore, although the specific gravity of brine is higher than that of water, the product of specific heat and specific gravity for any given brine solution is less than one per cent, meaning that a given volume of brine will absorb less heat per degree Fahr. rise in temperature than the same volume of water. According to the Smithsonian Physical Tables, the conductivity of brine is less than that of water and its viscosity is higher, both of which factors would tend to make the quenching speed of brine less than that of water.

In fact, the only reason which the writer has been able to find for the greater quenching speed of brine is that there is less liability of a steam blanket forming around the piece being quenched. It would seem that this property can be due only in part to the higher boiling point of brine, as the boiling point is raised only about 9 degrees Fahr. for a 25 per cent solution of brine. The claim has been made by some steel treaters that a piece of steel can be made harder by quenching in pure water than in brine and it would seem that this might be true of a small piece which could be moved about rapidly so that the steam blanket would not form.

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel?

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

QUESTION NO. 88. What are the flash and fire points of the principal vegetable, animal and mineral oils?

ANSWER. The following list gives the latest determinations of the principal vegetable, animal and mineral oils:

Name	Flash Degrees Fahr.	Fire Degrees Fahr.
Corn	480	635
Cottonseed	582	644
Prime Lard	530	644
	600	...
No. 2 Lard	419	468
Boiled Linseed	378	572
Raw Linseed	525	644
Neatsfoot	439	523
Olive	451	541
Light Mineral Oil (25 degrees Beaume)	410	475
75 per cent Light Mineral, 225 per cent Neatsfoot	410	471
75 per cent Light Mineral, 50 per cent Lard	410	489
50 per cent Light Mineral, 50 per cent Lard	423	513
25 per cent Light Mineral, 75 per cent Lard	441	543
Sperm No. 1	428	518
Sperm No. 2	486	574

QUESTION NO. 89. What are the melting points of the principal chemical elements?

ANSWER. The following gives the latest determinations of melting points of the principal chemical elements, supplied by the United States bureau of standards:

Element	Degrees Cent.	Degrees Fahr.	Element	Degrees Cent.	Degrees Fahr.
Aluminum	659	1218	Mercury	—39	—38
Antimony	630	1166	Molybdenum	2500	4532
Barium	850	1562	Nickel	1452	2646
Bismuth	271	520	Nitrogen	—210	—346

Element	°C	°F	Element	°C	°F
Boron	2200	3992	Oxygen	—218	—360
Calcium	810	1490	Palladium	1549	2820
Carbon	3600	6510	Phosphorus	44	111
Chlorine	—102	—151	Platinum	1755	3191
Chromium	1520	2768	Potassium	62	144
Cobalt	1480	2696	Silicon	1420	2588
Copper	1083	1981	Silver	960	1761
Gold	1063	1945	Sodium	97	207
Hydrogen	—259	—434	Sulphur Sl	113	236
Iodine	113	236	Tantalum	2850	5160
Iridium	2350	4262	Tin	232	450
Iron	1530	2786	Titanium	1800	3272
Lead	327	621	Tungsten	3000	5430
Magnesium	651	1204	Vanadium	1720	3128
Manganese	1260	2300	Zinc	419	787

QUESTION NO. 90 Please give the temperatures and corresponding temper colors used in the drawing of carbon steel.

ANSWER. The following list gives the temperatures and corresponding temper colors produced by heat in the drawing of carbon steel.

Cent. degrees	Fahr. degrees	Colors
215.6	420	Very Faint Yellow
221.11	430	Very Pale Yellow
226.67	440	Light Yellow
232.23	450	Pale Straw Yellow
237.78	460	Straw Yellow
243.34	470	Deep Straw Yellow
248.9	480	Dark Yellow
254.45	490	Yellow Brown
260	500	Brown Yellow
265.56	510	Red Brown
271.11	520	Brown Purple
276.67	530	Light Purple
282.23	540	Full Purple
287.78	550	Dark Purple
293.34	560	Light Blue
298.9	570	Dark Blue

QUESTION NO. 91. Please state the temperatures and corresponding colors used in hardening carbon steel.

ANSWER. The following are the latest determinations giving the temperatures and corresponding colors in hardening carbon steel.

Cent. degrees	Fahr. degrees	Colors
400	752	Red Heat, visible in the dark
474	884	Red Heat, visible in the twilight
525	977	Red Heat, visible in the daylight
581	1077	Red Heat, visible in the sunlight
700	1292	Dark Red
800	1472	Dull Cherry Red
900	1652	Cherry Red
1000	1832	Bright Cherry Red
1100	2012	Orange Red
1200	2192	Orange Yellow
1300	2372	Yellow White
1400	2552	White Welding Heat

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

FATIGUE FAILURE OF METALS. By C. F. Jenkin in *Proceedings* of the Royal Society (London), No. 1034 A, page 121 (1923).

The above article offers a theory to explain the mechanism of fatigue failure up to the yield point in which it is assumed that some of the crystals are initially stressed, and that the fatigue range is the same as the elastic range. It does not explain the effect of test speed or deviations from Hooke's law. It has been applied only to wrought iron, steel, nichrome and carbon and is probably not applicable to brittle metals.

CONTROLLING CAST-IRON HARDNESS. By S. J. Felton in *Foundry* No. 51, page 321 (1923).

This article states that metallographic study showing the different constituents indicates the causes of hardness. Control methods are outlined. It further states that close-grained iron is not likely to be porous but has large internal shrinkage.

EFFECT OF ANNEALING GRAY IRON. By J. F. Harper and R. S. MacPherran, in *Foundry* No. 51, page 177 (1923).

The authors of the above article state that test bars heated at different temperatures for various lengths of time show changes in strength and hardness caused by annealing. Charts are given showing the results and micrographs shown.

THE IMPORTANCE OF PHYSICAL CHEMISTRY IN THE METALLURGY OF IRON. By R. Schenck in *Stahl und Eisen,* No. 43, pages 65 and 153 (1923).

In this article the author discusses the importance of the phase rule and its applications in blast furnace practice. Illustrations of curves and calculations are given.

PROGRESS IN THE MANUFACTURE OF MARTIN STEEL. By A. Barberot in *Revue de Metallurgie,* No. 20, pages 1 and 95 (1923).

This article gives a detailed review of the development of the process and the equipment used, from the beginning until the present day.

NEW METHOD FOR CASE HARDENING. By Frank Hodson, in *Chemical and Metallurgical Engineering*, No. 28, page 308, (1923).

In this article the author shows how the carbon in the gas in the carburizing pots is materially increased by means of a catalyzer. The advantages in the use of this method are given.

LOW-TEMPERATURE BRITTLENESS IN SILICON STEELS. By N. P. Pilling in *Transactions* of American Institute of Mining and Metallurgical Engineers, No. 1220-S, (1923).

This article states that the brittleness of silicon steel is an inherent property of iron, modified by the alloyed silicon. Commercial silicon steel becomes brittle when the silicon content exceeds 4.2 per cent. Temporary ductility may be obtained by carrying on cutting operations at temperatures slightly above the atmosphere, the temperature depending on the steel composition. Brittleness is only slightly modified by heat treatment. The purest iron shows a similar brittleness at about 130 degrees. Silicon and aluminum raise, and manganese lowers the critical ductility temperature.

MALLEABLE-IRON METALLURGY. By M. M. Marcus, in *Foundry* No. 50, page 995, (1922).

The above article states that on account of the lower carbon and silicon contents and consequent higher melting point, cast iron for malleablizing must be poured more rapidly and at a higher temperature than gray iron. There is also discussed the effect of varying amounts of carbon, silicon and manganese, and data are given on annealing.

OPEN-HEARTH STEEL PRACTICE. By Willis McKee, in *Foundry* No. 50, page 990, (1922).

This article states that combustion that is imperfect or delayed until after the gases have passed over the charge is the greatest cause of low thermal efficiency, and also causes damage to uptakes, slag pockets, and regenerators from overheating. The blowtorch principle, using ports of such design that the air and gas mix before entering the hearth chamber, prevents this trouble. The entering velocity must be high to keep down combustion in the ports. The melting time is greatly shortened. In using this method it dispenses with gas regenerator chambers when producer gas is used, and to make the gas near the furnace and conduct it through insulated steel mains. This would simplify construction and should give additional fuel economy. The design of ports is discussed, with diagrams.

METALLURGICAL APPLICATIONS OF PHYSICAL CHEMISTRY. By C. H. Desch in *Journal* of Chemical society, No. 123, page 280, (1923).

In this article the author has selected a number of subjects to indicate the large field for co-operation between the physical chemist and the metallurgist.

Reviews of Recent Patents

1,449,206. Method of and Apparatus for Heavy Spot Welding. James M. Weed, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York.

This invention refers to a method of spot welding plates or structural parts by compressing the plates between electrodes through which a welding current is passed, characterized by the fact that the surfaces to be welded are provided with a coating adapted to furnish a relatively high contact resistance between the plates and by the fact that the surfaces of the plates where they are engaged by the welding electrodes are made to furnish a relatively low contact resistance.

1,449,251. Electric-Furnace Regulator. John A. Seeds, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York.

This patent relates to a regulating apparatus for an electric arc furnace having co-operating electrodes, comprising a furnace circuit, means for feeding at least one of said electrodes toward the co-operating electrode to maintain an arc, and means for rendering said feeding means inoperative when the voltage between said electrodes falls below a predetermined value, while the supply voltage in said furnace circuit is as great as a said value.

1,449,307. Electric Furnace. Leone Tagliaferri, Genoa, Italy.

This invention refers to an electric furnace for melting metal, which consists of two sets of electrodes, the separate electrodes of one set being each connected to the source of current to be in one phase thereof and the electrodes of the other set being connected to the neutral of the source of current and to the body of the furnace, and said electrodes being positioned so that the axis of one set cross the axis of the other set and each set being movable relative to the other set and the body of the furnace, so that arcs may be produced either between the two sets of electrodes above the bath or the one set of electrodes and the metal carried by the body of the furnace.

1,449,319 Process of Melting and Deoxidizing Steel. Albert E. Greene, Seattle, Washington.

This relates to a method of treating iron or steel which consists in melting the same on a basic hearth with an oxidizing slag, remov-

ing said slag and applying to the bath a finishing slag comprising lime and silica in approximately such proportions as to form a neutral mixture which is neither strongly acid nor strongly basic, and finishing the metal with said slag.

1,449,338. Alloy and Process of Making the same. Frederick T. McCurdy, Kokomo, Ind., assignor to Haynes Stellite Company, a corporation of Indiana.

This patent refers to a metal alloy comprising cobalt, a metal of the chromium group, and tantalum, the cobalt and metal of the chromium group each being present in the proportion of at least 10 per cent. and the tantalum being not substantially in excess of 5 per cent.

1,449,369. Welding Apparatus. James L. Anderson, Bayonne, N. J., assignor, by mesne assignments to Air Reduction Company, Inc., New York City, a corporation of New York.

This invention refers to a welding apparatus which provides for a means for holding sheet metal parts with their edges in relation to be fused by the welder, comprising one or more electromagnets and armatures, constituted as a support beneath the work and separated clamping arms above, to grip the part to be united while exposing the seam, the lines of force passing through the work between the magnet poles at one side and the armatures at the other.

1,449,373. Corrosion-Resistant Alloy. Wesley J. Beck and James A. Aupperle, Middletown, Ohio, assignors to the American Rolling Mill Company, Middletown, Ohio, a corporation of Ohio.

This patent refers to a workable iron alloy highly resistant to destructive corrosion under atmospheric conditions, and fabricated into forms for use under exposure to such conditions, containing silicon ranging upward from substantially two per cent to a percentage not so high as to render it unworkable and containing more silicon than any other alloying metal.

1,449,546. Iron Purifying and Balling Furnace. Oswald S. Pulliam, New York City.

This patent refers to a furnace which comprises a rotatory hearth, and agitating means movable in a circular path over the surface of said hearth, and in contact therewith.

1,449,637. Process of Welding Copper to Iron. Guglielmo Roberto Tremolada, Detroit, Mich., assignor to Detroit Air Cooled Car Company, Detroit, Mich., a corporation of Delaware.

This patent relates to a process which consists in subjecting copper containing an iron alloy to molten iron in a suitable mould, whereby the copper may be fused through the heat of said molten metal and become an integral part of the casting formed from the iron in said mold.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

ACKER, L. F., (M-8), No. 2 Wellsford St., Pittsburgh, Pa.
BEDEL & Co., (Sub.), St.Etienne, Paris, France.
BELLRINGER, S. M., (M-8), 161 S. Church St., Waynesboro, Pa.
BLUE, A. A., (M-8), c/o The Duff Mfg. Co., Pittsburgh, Pa.
BOEGEHOLD, A. L., (M-7), General Motors Research Corp., Dayton, Ohio
BROWN, H. A., (M-8) c/o British Embassy, Washington, D. C.
DONAHUE, J. L., (M-8) 66½ Whittier Ave., Providence, R. I.
ERTEL, JR., J. C., (M-6), 226 Adelaide St., Indianapolis, Ind.
FERNOLD, E. H., (Jr-8) Saco-Lowell Shops, Lowell, Mass.
GIBBONS, JAMES, (M-4), 436 Milwaukee St., Milwaukee, Wis.
GILL, R. L., (A-7), Room 802-109 N. Dearborn St., Chicago, Ill.
GOLDCAMP, CYRIL F., (M-8), 337 Atwood St., Pittsburgh, Pa.
HALE, FRANK L., (M-8), 137 Monterey Ave., Pellham, N. Y.
IHLEN, ALF, (M-5), c/o Strommenst Verksted, Strommenst, Norway.
LINCOLN, THOMAS J., (M-8), 59 Judd St., Bristol, Conn.
LITTELL, NELSON, (M-8), 110 East 42nd St., New York City.
NEW DEPARTURE MFG. CO., (S-6), Plant "A" Bristol, Conn. Att.: Carl Anderson.
NEW DEPARTURE MFG. CO., (S-6), Plant "C," Elmwood, Conn. Att.: F. Casey.
NEW DEPARTURE MFG. CO., (S-6), Forge Plant, Bristol, Conn. Att.: F. Mayer.
NEW DEPARTURE MFG. CO., (S-6), Plant "C," Elmwood, Conn. Att.: Patrick Pepper.
NEWELL, R. F., (A-6), c/o General Electric Co., 120 Broadway, New York City.
ROBINSON, DON M., (M-5), 422 Main St., So. Weymouth, Mass.
SCHEIB, WALTER H., (M-7), c/o Buell-Scheib-Mueller, Inc., Columbia Bank Bldg., Pittsburgh, Pa.
SIMMONS, CHARLES B., (M-8), c/o New Departure Mfg. Co., Bristol, Conn.
STEINREICH, WM. E., (M-8), c/o New Departure Mfg. Co., Laboratory, Bristol, Conn.
TIMM, F. M., (M-9), 1233 Jackson St., Hammond, Ind.
VAN NORMAN, E. R., (M-5), 27 Gould Ave., Caldwell, N. J.
WATTEL, CARL F., (M-9), 296 Sherwood Ave., Rochester, N. Y.
WHITNEY MFG. CO., (S-8), Hartford, Conn.

CHANGES OF ADDRESS

ARMITAGE, A. N., from c/o Laboratory Mesta Machine Co., Pittsburgh, Pa., to 4551 Huntington Drive, No., Los Angeles, Cal.
ARNESS, W. B., from 2627 Nicollet Ave., Minneapolis, Minn., to Hotel Sydney, Gary, Ind.
ARTHUR, WALTER, from Reeds, Mo., to Socorro, N. Mex.
BEGLEY, J. P., from 1448 E. 72nd Pl., to 6930 Crandon Ave., Chicago Ill.
BLAKESLEE, MARSHALL E., from Fafnir Bearing Co. New Britain, Conn., to 2434 Orin Drive, Oakland, Cal.

BOWERS, WHEELER, from 464 E. 129th St., Cleveland, O., to 1082 E. 141st St., Collinwood, O.

BROWN, WALTER, from Kent Owens Machine Co., 928 Wall St., to 362 Summit St., Toledo, O.

CAMPBELL, C. M., from Pioneer Alloy Products Co., to 1195 East 124th St., Cleveland, O.

CHABOT, J. M. T., from 115 Court St., to 1418 Magazine St., Charleston, W. Va.

CONNER, C. M., from 2224 Market St., to 305 Wesley Bldg., 1701 Arch St., Philadelphia, Pa.

CROSBY, V. A., from 630 N. Walnut, to c/o Studebaker Corp., South Bend, Ind.

DEGOWIN, W. R., from 1432-24th St., to 12057 Indiana Ave., Detroit, Mich.

DIETRICH, J. A., from 5656 Rogers St., to 2660 Webb Ave., Detroit, Mich.

DIXON, E. O., from 895 S. Pierce St., Milwaukee, Wis., to 12121 Eggleston Ave., Chicago, Ill.

GANSER, J. N., from 415 S. Main St., to c/o Acme Machine Co., Mishawaka, Ind.

GELDER, R. H., from 176-15th Ave., Columbus, O., to 704 E. Montgomery Ave., Ashland, Ky.

GLAB, PETER, from 502 E. Jefferson St., to 260 Fremont Street, Syracuse, N. Y.

GRAHAM, C. A., from 14656 Scripps Ave., to c/o Studebaker Corp., Plant No. 3, Detroit, Mich.

GREAVES, ROBT. K., from 1336 W. Washington Blvd., Chicago, Ill., to 1620 W. Lafayette Blvd., Detroit, Mich.

GRIFFITHS, E., from 59-16th Ave., Columbus, O., to Union Carbide & Carbon Research Lab., Inc., Thompson Ave. & Manby St., Long Island City, N. Y.

GWILLIAM, John, from c/o The Gwilliam Co., 253 W. 5th St. New York, to 23 Flatbush Ave., Brooklyn, N. Y.

HAZEN, ARTHUR J., from 30 Union St., to 517 Union St., Hartford, Wis.

HOLMES, J. Q., from Y. M. C. A., to 312 W. 8th St., Anderson, Ind.

HOWE, M. J., from 3915 Congress St., to 1706 Jackson Blvd., Chicago, Ill.

HULBERT, L. G., from 4524 Avery Ave., to 1670 Calvert, Detroit, Mich.

JENKS, W. E., from 11417 Continental Ave., to 13415 Edgwood Ave., Cleveland, O.

JOHNSON, P. A., from 4933 N. Tripp Ave., to 3701 N. Drake Ave., Chicago, Ill.

KRUGER, LOUIS R., from P. O. Box 256, Michigan City, Ind., to 817 W. Washington Blvd., Chicago, Ill.

LARCHER, A. J., from 15235 Center Ave., Harvey, Ill., to 305 Olive St., Blue Island, Ill.

LOCKE, A. C., from 19 Pleasant St., to 22 Sessions St., Bristol, Conn.

LOUDENBACK, C. I., from 2407 First National Bank Bldg., to 2725 Carter Ave., Detroit, Mich.

MAROT, E. H., from 7404 Hanover St., Detroit, Mich., to 2506 Virginia Park, Detroit, Mich.

MARTELL, FRED, from 1526 S. Main St., to 930 E. Donald St., South Bend, Ind.

McOMBER, M. F., from 924 E. Liberty St., to 924 Maryland, East Liberty Station, Pittsburgh, Pa.

MITCHELL, D. E., from 2377 E. Grand Blvd., to c/o Dodge Bros. Co., Detroit, Mich.

MOODY, CHESTER, S., from Minn. Steel & Mach. Co., 29th & Minnehaha, Minneapolis, Minn., to C. L. Best Tractor Co., San Leandro, Cal.

MORANTY, A. F., from 3938 Livernais Ave., to 1290 Lenox Ave., Detroit, Mich.

ODEMAR, F. W., from 305 Merchants Bk. Bldg., to 914 N. Capitol Ave., Indianapolis, Ind.

OLSEN, CARL L., from 1310 Beville Ave., to 923 Eastern Ave., Indianapolis, Ind.

PAGE STEEL & FLAGG CO., from 111 Court St., to 219-221 Water St., New Haven, Conn.

PERRETTO, ROBT., from 9021 Wilson to 9724 Chenlot, Detroit, Mich.

ROBERTS, J. H., from Atlas Steel Corp., to c/o Shorewood, Country Club, West Lake Road, Dunkirk, N. Y.

SCHMITT, FRANK, from 811 W. Lafayette Blvd., to c/o International Mfg. Co., Detroit, Mich.

SHEPARD, R. L., from 141 Montana W., to c/o Shepard Co., Charlevoix and Hart Aves., Detroit, Mich.

STENGER, BERNARD H., from 1620 John St., Cincinnati, O., to 12632 Edmonton Ave., Cleveland, O.

STUART, C. W., from 53 Garfield, to c/o Dodge Bros. Co., Detroit, Mich.

TOPHAM, R. A., from New American House, 42 Andrews St., Lynn, Mass., to 162 So. Common St., West Lynn, Mass.

VOLKOFF, VLADIMIR JR., from 199½-8th St., Troy, N. Y., to 104 Main St., Waynesboro, Pa.

WAGAR, T. E., from 956 Melbourne Ave., to 3773 Wager Ave., Detroit, Mich.

WHITE, W. H., from 56 Murray St. New York City, to District Manager, Atlas Steel Corp., 627 Hanna Bldg., Cleveland, O.

WILLIAMS, J. J., from 73 Orient St., to 35 Orient St., Meriden, Conn.

ZIMMERLI, F. P., from 1585 Delaware Ave., to 6438 Trumbull Ave., Detroit, Mich.

ZORNIG, MAJOR H. H., from 305 Mt. Auburn, Watertown, Mass., to Picatinny Arsenal, Dover, N. J.

MAIL RETURNED

BACH, A. D., Atlas Steel Corp., 725 St. Clair Ave. NE.,Cleveland,O.

CARMODY, ARTHUR J., 221 Market St., Hartford, Conn.

CLARK, H. A., 1674 Pingree Ave., Detroit, Mich.

FREDERICK, J. B. Barber Colman Co., Rockford, Ill.

McMANUS, W. H., 4417 2nd Ave., Detroit, Mich.

RALSTON, A. L., 1734 Lafayette Blvd., Detroit, Mich.

WOLF, ERNEST, Lewis Institute, Chicago, Ill.

GIZOWS, J., 1951 W. Madison St., Chicago, Ill.

ZWAHL, C. E., 27 East Willis Luialdo Apt., Detroit, Mich.

TRANSACTIONS

of the

American Society for Steel Treating

Vol. IV **Cleveland, October, 1923** **No. 4**

INITIATIVE

ELBERT HUBBARD rightly said that "the world bestows its big prizes, both in money and honors, for but one thing. And that is *Initiative.*"

What is Initiative? He answers that "it is doing the right thing without being told. But next to doing the thing without being told is to do it when you are told once. That is to say, carry the message to Garcia. Those who can carry a message get high honors, but their pay is not always in proportion. Next, there are those who never do a thing until they are told twice. Such get no honors and small pay. Next, there are those who do the right thing only when necessity kicks them from behind, and these get indifference instead of honors, and a pittance for pay. This kind spends most of its time polishing a bench with a hard luck story.

"Then, still lower down in the scale than this, we have the fellow who will not do the right thing even when someone goes along to show him how and stays to see that he does it. He is always out of a job, and receives the contempt he deserves, unless he happens to have a rich Pa, in which case Destiny patiently awaits around the corner with a stuffed club."

How many do you know who fits each class? The successful man can only come from, and belong to, the first. He must have initiative to climb high on the ladder of success.

REPORT OF FIFTH ANNUAL CONVENTION

THE October issue of TRANSACTIONS goes to press on the eve of the fifth annual convention of the Society. A complete report of convention activities will appear in the November issue of TRANSACTIONS.

HENRY MARION HOWE MEMORIAL SERVICE

AT THE Episcopal Cathedral of St. John, the Divine, One hundred and tenth street and Amsterdam avenue, New York City at 5:00 p. m. on Thursday, Oct. 25, 1923, will be held a memorial service for the late Dr. Henry Marion Howe, president of the American Institute of Mining Engineering in 1893, in whose memory the institute has recently established the Henry Marion Howe Lecture.

The memorial service will be largely musical, by the Cathedral organist and choir, with short addresses. Dr. Nicholas Murray Butler, president of Columbia university, has been asked to be one of the speakers. Doctor Howe was a vestryman in an Episcopal church in this diocese. He combined the qualities of the great scientist with those of a devout christian. Bishop Manning and Dean Robbins idealized the service as an expression of the harmony which can and does exist fundamentally between science and religion, when understood profoundly.

After conference between Bishop Manning and Judge Gary, as president of the American Iron and Steel institute, the date of the service was selected so as to coincide with the autumn meeting of the American Iron and Steel institute. Owing to the absence of Mrs. Howe, it was deemed best not to hold the service at the time of the annual meeting of the American Institute of Mining Engineering last February. The directors of the American Institute of Mining Engineering have, however, appointed a committee to co-operate with Dean Robbins in arranging the details of the service, and it is hoped that many members of the institute in the East will attend it. The Cathedral is more than large enough to seat all who can and will come. Everyone is invited who is interested or attracted by the beauty of the service, or desires to join in this token of respect to our late distinguished past-president.

GEORGE KIMBALL BURGESS
National President of the American Society for Steel Treating

Officers of The American Society for Steel Treating

1923-24

President

GEORGE KIMBALL BURGESS
Director, Bureau of Standards
Washington, D. C.

First Vice President

W. S. BIDLE
President, W. S. Bidle Co.,
Cleveland, Ohio

Second Vice President

ROBERT M. BIRD
Engineer of Tests, Bethlehem Steel Co.,
Bethlehem, Pa.

Secretary

W. H. EISENMAN
4600 Prospect Avenue
Cleveland, O.

Treasurer

ZAY JEFFRIES
Research Bureau, Aluminum Company of America
Cleveland, O.

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J. FLETCHER HARPER
Research Engineer, Manufacturing
Department
Allis-Chalmers Mfg. Co.,
Milwaukee, Wis.

NEW OFFICERS

THE tellers of election have counted the ballots cast by the membership of the American Society for Steel Treating and the following new officers have been elected: President, Dr. George K. Burgess, director, Bureau of Standards, Washington, D. C.; second vice president, Robert M. Bird, engineer of tests, Bethlehem Steel Company, Bethlehem, Pa.; treasurer, Zay Jeffries, research bureau, Aluminum Company of America, Cleveland; director, J. Fletcher Harper, research engineer, Allis-Chalmers Mfg. Company, Milwaukee, Wis.

The board of directors of the society will be composed of the newly elected officers and the following: First vice president, W. S. Bidle, president, W. S. Bidle Company; secretary, W. H. Eisenman, 4600 Prospect avenue, Cleveland;

W. S. BIDLE
First Vice President of the Society

ROBERT M. BIRD
Second Vice President of the Society

W. H. EISENMAN
National Secretary of the Society

ZAY JEFFRIES
National Treasurer of the Society

T. D. LYNCH
Past President
National Director of the Society

F. P. GILLIGAN
Past President
National Director of the Society

S. M. HAVENS
National Director of the Society

J. FLETCHER HARPER
National Director of the Society

director, T. D. Lynch, past-president, manager, M. & P. engineering department, Westinghouse Electric & Mfg. Company, East Pittsburgh; director, F. P. Gilligan, past-president, secretary-treasurer, Henry Souther Engineering Company, Hartford, Conn.

The new officers will begin their duties at the close of the annual convention of the Society at Pittsburgh, October 8 to 12, 1923.

The report of the tellers of election is as follows:

August 15, 1923.

To the Secretary,
American Society for Steel Treating,
4600 Prospect Avenue,
Cleveland, Ohio.

The Committee of Tellers begs to submit the results of the balloting by the membership for National Officers of the American Society for Steel Treating.

These ballots were received by the Committee, opened, examined, and counted in the National Headquarters of the Society at 4600 Prospect Avenue, Cleveland, Ohio.

The signature of each voting member written on the outside of the envelope had previously been verified by Secretary W. H. Eisenman, and found to be correct.

The tabulation of the count is as follows:

	For	Scattering	Defective	Total
For President				
One Year				
G. K. Burgess	919	4	36	959
For Second Vice President				
Two Years				
Robt. M. Bird	922	1	36	959
For Treasurer				
Two Years				
Zay Jeffries	920	3	36	959
For Director				
Two Years				
J. F. Harper	896	27	36	959

Respectfully submitted,
Committee of Tellers,
C. W. SIMPSON,
C. M. CAMPBELL,
C. G. SHONTZ, Chairman.

THE THEORY IN QUENCHING STEELS

By Kotaro Honda

Abstract

The author of this paper, a well known authority on the metallurgy of iron and steel, has reviewed in considerable detail the theory of the mechanism and principles involved in the quenching of steels.

Quenching cracks are closely studied and the author points out that the generally accepted cause of the cracking of high carbon steels by quenching in water, is not as evident as has been supposed. The nonuniform distribution of temperature and the difference in martensite expansion of adjacent parts during quenching, are not alone the causes of quenching cracks, because, as the result of the author's experiments it was found that cracking occurs only when the quenching temperature exceeds the A_1 point. The cracks, therefore, must have some connection with the A_1 transformation. The author develops the theory in this connection as based upon experimental data. Hardness tests of specimens quenched from various temperatures are included in this paper. In conclusion the author suggests a remedy for eliminating quenching cracks.

Principle of Quenching

THE quenching of a steel in its heat treatment originally means the suppression of a transformation by a rapid cooling. This rapid cooling is usually obtained by plunging a heated steel in cold water or oil. If a metal possessing a transformation at a high temperature be heated above this temperature and then cooled very rapidly, the transformation is partially or wholly arrested. The metal requires a certain time to perform a transformation, and if this time is insufficient, the transformation cannot progress at all, or goes on a little, before the metal cools to room temperature; but any transformation taking place very easily at high temperature scarcely goes on at room temperature, owing to the great viscosity of the metal at low temperature. Thus, by

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water quenching a metal possessing a transformation, from a temperature above the transformation point, the state or the phase at the high temperature can be preserved at room temperature. Hence we can easily study its structure microscopically. This is the principle of quenching and is widely used in the science of metallurgy; its absolute validity is generally admitted.

Quenching of Steels

Take for the sake of simplicity, the case of quenching of a 0.90 per cent carbon steel. Above the A_1 point, the steel has an austenitic structure consisting of a solid solution of carbon in γ-iron, and below it a pearlitic structure consisting of a mechanical mixture of ferrite and cementite forming the well-known lamellar distribution. Hence by quenching the steel above the A_1 point, it is to be expected to have an austenitic structure, or if the quenching is not sufficiently effective, a pearlitic structure. Contrary to our expectation, we obtain a structure quite different from either of them. This structure consists of very fine needle-shaped crystals known as martensite; being a very hard homogeneous phase consisting of a solid solution of carbon in α-iron. By X-ray analysis, Dr. Westgren[1] has shown that in the austenitic region, i. e., above the A_3 point, iron has a face-centered cubic lattice, but below it a cubic centered, thus the A_3 transformation in iron being the change of atomic configuration from a face-centered cube to a cube-centered, or vice versa, and that the atomic configuration in martensite is the body-centered cube as in α-iron, but differs from the latter in taking carbon atoms in the interspace of the cubic lattice. From the diffusion of the spectrum lines, he also concludes that individual crystals constituting the martensitic structure are very fine, each containing only several hundreds of atoms. There is thus no doubt that martensite is a solid solution different in phase from austenite, differing of course from pearlite.

If by quenching a steel, neither austenite nor pearlite, but martensite, is obtained, the principle of quenching is violated, and hence numerous results of investigations hitherto made by many metallurgists in observing the microstructure of quenched metals and alloys may not be true. The formation of martensite by

1. Iron and Steel Institute, 1921, No. 1; 1922, No. 1.

quenching is thus a very important and serious problem in metallurgy; hence it is much to be desired that if possible, the above problem will be so explained as to conform with the principle of quenching.

The Theory of Quenching

From the structural point of view, the A_1 transformation consists of

$$\text{austenite} \rightleftarrows \text{pearlite}.$$

but according to the present writer,[2] this shows only the result of the transformation, and the change itself consists in reality of the stepped change, that is,

$$\text{austenite} \rightleftarrows \text{martensite} \rightleftarrows \text{pearlite}$$

or

$$\text{solid solution } \gamma \rightleftarrows \text{solid solution } \beta \rightleftarrows \text{Fe} + \text{Fe}_3\text{C}.$$

During a slow cooling, at the A_1 point, austenite first changes into martensite, and the latter being at the high temperature, changes immediately into pearlite, the result being the same as

$$\text{austenite} \rightarrow \text{pearlite}.$$

During a very rapid cooling, such as quenching, the change from austenite to martensite is so far retarded that it begins to take place at below 300 degree Cent. (572 degrees Fahr.), and when this change is completed, the specimen is nearly at room temperature, and hence the second change from martensite to pearlite cannot progress, owing to the great viscosity of the specimen at room temperature. Thus by quenching the steel in water, martensite is obtained. This explanation does not at all contradict the principle of quenching.

Since during cooling, the change from austenite to pearlite always occurs through an intermediate phase martensite, it is natural to assume that during heating, the A_1 transformation, that is, the change from pearlite to austenite takes place through martensite, unless some negative facts are found.

According to the above theory of quenching, the perfect quenching is obtained when the first change in the stepped transformation, austenite→martensite, completely takes place, and the second change, martensite→pearlite, is completely suppressed. In the case of a less rapid cooling, the first change occurs at a

2. *Science Reports* 8 (1919), 181; 11 (1922), 489. K. Honda and T. Matsushita. *Science Reports* 8 (1919); K. Honda and S. Idei; *Science Reports* 9 (1920), 491.

little higher temperature than in the above case, and therefore the second change partially progresses, resulting in a martensitic structure mixed with pearlite (troostite in actual case). Since the hardnesses H of austenite, martensite and pearlite satisfy the following relation,

$$H_{\text{austenite}} < H_{\text{martensite}} > H_{\text{pearlite}}$$

the hardness of the martensite mixed with pearlite is less than that of pure martensite. This is the case of an imperfect quenching.

In the case of an extremely rapid cooling, not only the second change is completely suppressed, but even the first change is partially suppressed. We then obtain a martensitic structure mixed with austenite, the hardness of which is less than that of pure martensite. This is the case of a too severe quenching. In such a case, however, a little tempering at a temperature below 100 degrees Cent. which accelerates the change of the remaining austenite into martensite, increase its hardness slightly.

Equilibrium Diagram of Iron-Carbon System and the Stepped Transformation

Fig. 1 is that portion of the constitutional diagram of the iron-carbon system, which has the connection with the A_1 transformation. The A_3 point of pure iron is lowered by the addition of carbon along the line A_3E, till it reaches the eutectoid horizontal A_1C at point E. Above the eutectoid concentration E, the A_3 line coincides with the eutectoid line EC. EB is the solubility line of cementite in γ-iron or austenite. The dotted horizontal is the A_2 line; this line is so drawn, since the A_2 transformation is not the change of phase.

From the equilibrium diagram, it is to be concluded that along line A_3E, double processes consisting of the A_3 change and the precipitation of ferrite begins to take place, and that along line EC, in which the A_3 point falls, the above double processes occur at the same temperature. Since the A_3 transformation during cooling consists of the change of configuration in iron atoms from the face-centered cube to the body-centered, carbon being still present as a solid solution, the first change of the double processes in the case of steels is nothing but the change, austenite→martensite, and the second change, that is, the precipitation of ferrite

from martensite is the change, martensite→pearlite. Thus the double processes just referred to are the same as the stepped change before mentioned, that is,

austenite→martensite→pearlite

Suppose we cool a hypereutectoid steel from the austenitic region; on reaching line EB, cementite begins to precipitate from austenite and continues to do so, as the temperature falls, till the concentration of the remaining austenite reaches that of eu-

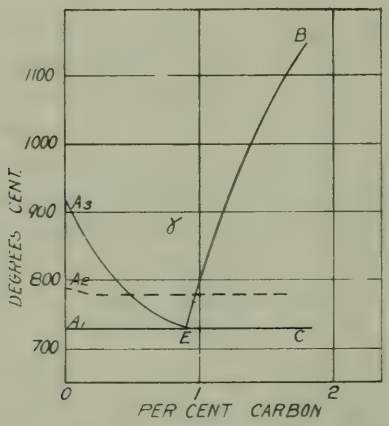

Fig. 1—Portion of Constitutional Diagram of the Iron-Carbon System

tectoid. At this point, the austenite makes the A_1 transformation, that is, the A_3 transformation immediately followed by alternate precipitations of ferrite and cementite in virtue of alternate supercoolings, giving rise to the well known lamellar structure. Thus the A_1 transformation here consists of the changes,

austenite→martensite→pearlite

Since the nature of the A_1 transformation is the same both for the hypo and hypereutectoid steels, it is to be concluded that for the whole carbon concentrations ranging from 0 to 6.7 per cent, the A_1 transformation must, in its nature, consist of the changes,

austenite→martensite→pearlite

On the other hand, if we cool the hypoeutectoid steel from the austenitic region, on reaching line A_3E, a small quantity of

austenite first makes the A_3 transformation, and then from this transformed product,—martensite—, the precipitation of ferrite follows. As the steel further cools, the remaining austenite gradually makes the same changes, till the concentration of austenite reaches the eutectoid at point E, where the remaining austenite makes the stepped change above referred to at the constant temperature.

We have seen in the above that the change, austenite→martensite, is in reality the A_3 transformation, and hence the heat of the change must be equal to that of the A_3 transformation in pure iron, a small allowance being made for the presence of the dissolved carbon atoms. Meuthen[3] found by his careful experiment, the heat of the A_3 transformation in pure iron to be 5.6 calories per gram. On the other hand, N. Yamada[4], directly measured the heat of transformation, austenite→martensite, for a eutectoid steel and found it to be 5.66 calories per gram of iron. Thus the coincidence between these two is very satisfactory.

In a former paper,[5] Dr. T. Matsushita has shown that in carbon steels, there exist two kinds of martensite α and β, the A_1 transformation during cooling taking place in the order.

Austenite→β-martensite→α-martensite →pearlite,

and that during a slow heating of a quenched steel, α and β martensites are tempered at about 180 and 280 degrees Cent. respectively. Since these martensites have both a body-centered cubic lattice with regard to iron atoms, the difference between them consists very probably in the mode of distribution of carbon atoms within the space-lattice of iron atoms. Thus strictly speaking, the A_1 transformation consists of three steps taking place one after the other.

The following analogy will also assist the understanding of the stepped transformation. Suppose a sphere to rest on a stepped stand of the form as shown in Fig. 2, and the stand to undergo a continuous vibration, which corresponds to the thermal condition of steel. Let us further suppose that the positions A and B in the stand are much more stable than that of C. The positions of the sphere at A, B and C are assumed to correspond to austenite, pearlite and martensite, respectively. When the equilibrium

3. Ferrum, 10, (1913), 1.
4. *Science Reports* 10, (1921), 453.
5. *Science Reports* 7, (1918), 43.

of the sphere at A is disturbed, the sphere falls at first to position C; if the vibration of the stand is considerable, it falls again to position B. These stepped falls are similar to the change of austenite to pearlite through martensite at high temperatures. If, however, during the fall of the sphere from positions A to C,

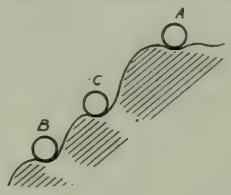

Fig. 2—Illustrating Stepped Transformation in Steel

the vibration of the stand decreases to a less intensity, the sphere will remain in equilibrium at position C. This case corresponds to the quenching of a steel.

In the same way, we may also conceive between two positions A and B two or more intermediate positions C_1, C_2, ... corresponding to α and β martensites, and so forth.

Troostitic and Sorbitic Structures

In the above theory of quenching, the perfect hardening is obtained, when the first change in the stepped transformation

austenite→martensite→pearlite

takes place completely and the second change is arrested, while an imperfect hardening corresponds to the case, when the first change goes on completely, but the second only partially. Fig. 3 is a diagram illustrating the mechanism of quenching and similar to that already given by Professor Sauveur in his well known textbook. *a* is the case of a slow cooling, where the change from austenite to pearlite takes place at a constant temperature of 700 degrees Cent. (1292 degrees Fahr). *b* is the case of the perfect hardening; here owing to a very rapid cooling, the change from austenite to martensite begins to take place at about 300 degrees Cent. and is completed near room temperature, the second change from martensite to pearlite being suppressed. *c* is the case of an imperfect quenching: owing to the slower rate of cooling than in

the last case, the first change begins to occur at about 450 degrees Cent. (842 degrees Fahr.) and when it is completed the specimen is still at a higher temperature, and hence the second change occurs, before it is cooled to room temperature. This change consists of the precipitation of cementite as fine colloidal particles from a martensitic solid solution; this structure, when polished, is

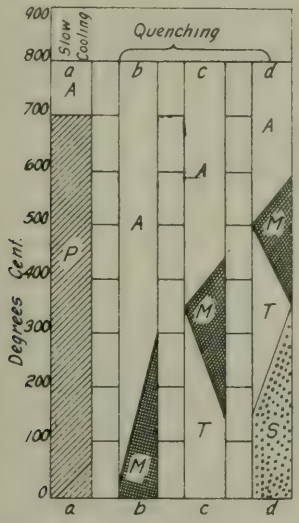

Fig. 3—Diagram Illustrating the Mechanism of Quenching

A—Austenite; M—Martensite; T—Troostite; S—Sorbite

easily etched in acid and by virtue of a minutely roughened surface due to the presence of cementite particles appears black, even to the naked eye. It is usually called, troostite.

In *d*, the cooling is still slower, and therefore, the first change occurs at a higher temperature than in the last case. Hence the formation of troostite takes place at higher temperature, so that if the further cooling to room temperature is conducted very slowly, troostitic particles coagulate to some extent by virture of the surface tension. This structure called sorbite, is less easily etched by acid than the troostitic structure, but more readily than the pearlitic structure.

By properly adjusting the rate of cooling, either one of three

structures, martensite, troostite or sorbite, can be obtained. Troostite and sorbite are the mechanical mixtures of ferrite and cementite, and therefore the same as pearlite in their nature.

In practice, it is usual to obtain troostite and sorbite by tempering quenched steels. The martensite, when left itself at room temperature, hardly changes into pearlite owing to the high viscosity of the material at this temperature, but when it is raised to 300 to 400 degrees Cent. the martensite slowly changes into troostite by the deposition of fine cementite particles. By raising the reheating temperature to 500 to 600 degrees Cent. for a certain interval of time, the coagulation of troostitic particles goes on to such a degree that the structure becomes sorbitic.

Besides the usual method of quenching and tempering, we frequently use a stepped quenching for obtaining a troostitic or sorbitic structure. The specimen is first heated above the A_1 point, then plunged into water and after a short interval of time, when the change from austenite to martensite is just completed, taken out. When during cooling in air, the change from martensite to troostite or further to sorbite goes on completely, the specimen is again quenched in water to arrest the change at this stage; we thus obtain a troostitic or sorbitic structure.

The velocity of a transformation in a pure metal generally decreases when it contains impurities or is alloyed with other metals. Thus the A_1 transformation goes on very slowly in special steels, such as nickel, chromium and manganese steels. In these steels, the structures, such as austenite and martensite, which are hardly or only obtainable by a very rapid cooling in the case of carbon steels, can be obtained by air cooling or at ordinary rates of cooling.

Quenching Cracks

It is a well-known fact that during the quenching of high carbon steels in water, cracks are often formed on their surfaces. The cause[6] is generally believed to be:

1. The nonuniform distribution of temperature in the specimen during quenching.

6. McCance, *Journal* of the Iron and Steel Institute, 1914, No. 11, pp. 235, 247.

2. The difference in martensitic expansion of adjacent parts during quenching.

A closer examination of the phenomenon shows, however, that the true cause is not so evident, as the sound due to cracking is often heard some ten seconds after quenching. The thermal stress is maintained so long as the temperature is not uniform throughout the specimen. For instance, in a short cylinder,[7] about 2 centimeters in thickness and height, the difference in temperatures between the interior and exterior parts, during the first stage of the quenching process, may amount to several hundred degrees, and consequently a great stress will result, but after about ten seconds it does not exceed 20 degrees and hence there is only a small residual stress. Again, at the moment of transformation of austenite into martensitic during cooling, considerable expansion in volume occurs. In the case of rapid cooling the transformation does not, however, take place at the same moment at the outside and the inside of the specimen. A great stress due to unequal martensitic expansion will result which may lead to cracking, although after several seconds, during which the A_1 transformation passes over the whole mass, this stress will also vanish.

If the cracks were due to the two causes above mentioned, why do they not take place during the first stage of quenching, when the specimen is undergoing a large amount of internal stress, and why do they take place after a lapse of time? It is, of course, conceivable that at a very high temperature, the material yields to an enormous thermal stress, and therefore this stress is partially released, in which case a thermal stress of considerable magnitude may result at room temperature, and may be the cause of the cracks occurring some ten seconds after quenching. During a very rapid cooling, such as quenching in water, the release of the stress, which requires a certain interval of time, is probably very small.

In order to show that the cause of quenching cracks is not pure thermal stress[8], the following experiment was made: Several cubes, 2 centimeters on each side, were made of steel containing 1.26 per cent of carbon. They were quenched in water from dif-

7. *Science Reports* 8 (1919), 36.
8. K. Honda and S. Idei, *Science Reports*, 9.

ferent high temperatures, and the quenching temperature at which cracking occurred, was observed.

The following table contains the result of the experiments:

Table I

Heating

	Quenching Temperature Degrees Centigrade					
	680	700	750	770	800	830
Remarks	No Crack	No Crack	No Crack	No Crack	Crack	Crack

Cooling

Quenching	Temperature Degrees Centigrade—Specimens first heated to 900 degrees Centigrade, then cooled and quenched					
	800	770	750	730	710	690
Remarks—	Crack	Crack	Crack	Crack	Crack	No Crack

From this table, it is seen that during heating the crack does not occur unless the quenching temperature exceeds 800 degrees Cent. During cooling from 900 degrees Cent. the quenching crack is always observed down to a temperature of 700 degrees Cent. and not observed at any lower temperature. This limiting temperature is much lower than that during heating. As is well known, the Ar_1 point is always lower by about 40 to 80 degrees Cent. than the Ac_1 point; hence, from the above result of quenching experiments, it may be concluded that during heating or cooling the crack occurs when, and only when, the quenching temperature exceeds the Ac_1 or Ar_1 point, respectively. Hence the cause of quenching cracks is not pure thermal stress caused by nonuniform distribution of temperature due to rapid cooling, because if such were the case, there would be no reason for the cracks occuring beyond the A_1 point. The cracks must, therefore, have some connection with the A_1 transformation.

In a quenching, cracks usually occur in ten to fifteen seconds after quenching in water; they can be distinctly detected by the sounds accompanying cracking. The same fact also indicates that the thermal stress is not the direct cause of cracking; because the cracking occurs after a lapse of time, where a greater part of the thermal stress due to the unequal cooling of the specimen passes off. As is well known, during cooling through the Ar_1 point, the specimen undergoes a considerable expansion due to the

A_1 transformation.[9] Since during cooling the outer portion is always at a much lower temperature than the inner portion, the former, during the said transformation, exerts a great impulsive

73	64	69	73	77	79
70	71	63	72	77	77
70	42	44	48	57	79
71	45	43	47	55	79
69	66	53	55	67	78
70	70	68	70	68	73

Fig. 4

75	72	70	74	74	77
69	68	67	69	70	72
68	65	68	68	65	69
68	67	68	67	69	70
70	68	65	67	70	75
73	72	73	69	73	76

Fig. 5

tension on the latter, and this may cause a crack in the specimen. The fact that cracks generally occur after the impulsive stress due to the Ar_1 transformation is passed over, shows that the impulsive stress is not the actual cause of quenching cracks.

Hardness Measurements of Quenched Steels

The result[10] of experiments on the measurement of hardness in quenched carbon steels by means of a Shore scleroscope will be next described. The specimens were tested in the form of a cube each side being 2.7 centimeters.

1. In a soft quenching, such as in oil from a temperature not exceeding 820 degrees Cent. the hardness of different specimens is greatest in the outer portion, and decreases from its periphery towards the center (Fig. 4).

2. In a medium quenching, such as that of a 0.91 per cent carbon steel at 780 degrees Cent. in water, or that of a 1.47 per cent carbon steel at 900 degrees Cent. in oil, hardness is nearly constant everywhere (Fig. 5).

3. In a hard quenching, such as that of a 0.68 per cent

9. K. Honda, *Science Reports*, 6, (1917), 203.
10. K. Honda and S. Idei, *Science Reports*, 9

carbon steel from 800 degrees Cent. or a higher temperature in water, the hardness is least in the outer portion and increases rapidly toward the center (Fig. 6).

4. When cracking takes place, lines of cracking cut equi-hardness curves almost orthogonally. The form of equi-hardness

72	75	76	78	78	75
78	75	90	88	79	77
75	88	95	91	87	86
75	90	93	93	90	85
79	90	92	89	85	82
75	78	86	82	77	75

Fig. 6

curves is elongated in a direction normal to the line of cracking (Figs. 7, 8, 9).

5. In the cubes, the equi-hardness lines become roughly circular or elliptical at a short depth from the surface.

6. Cracking occurs in most cases, when the temperature of the specimens falls nearly to that of the bath.

7. The hardness does not increase appreciably, so long as the quenching temperature is below the Ac_1 point. When the temperature increases beyond the beginning of the Ac_1 range, the hardness rapidly increases, reaches a maximum at about 820 degrees Cent. and afterward slightly decreases.

The explanation of these facts is as follows:

According to the theory of quenching, the A_1 transformation is a stepped change consisting of

$$\text{austenite} \rightarrow \text{martensite} \rightarrow \text{pearlite}.$$

But with regard to the volume per unit of mass, the relation is,

$$\text{martensite} > \text{pearlite} > \text{austenite}$$

for martensite is known to exist in a more dilated state than pearlite, and the latter in a more dilated state than austenite, as is seen from the expansion-temperature curves[11] at high tempera-

11. K. Honda, *Science Reports*, 6.

tures. Hence in the A_1 range, during slow cooling, the elongation is a differential effect of the expansion due to austenite→martensite, and of the contraction due to martensite→pearlite; during slow heating, the contraction is a differential effect of the expansion due to pearlite→martensite, and of the contraction due to martensite → austenite.

In quenching experiments, the rates of cooling in the outer and inner portions of the specimen differ considerably from each

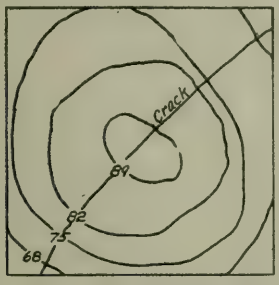

Fig. 7—Equi-hardness lines of a 1.0% Carbon Steel Quenched in Oil from 810 Degrees Cent.

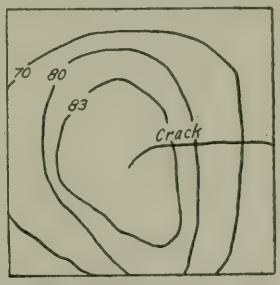

Fig. 8—Equi-hardness Lines of a 0.91% Carbon Steel Quenched in Water from 880 Degrees Cent.

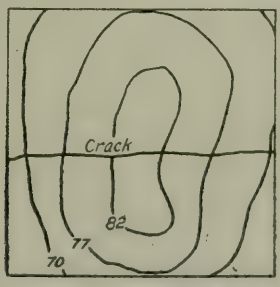

Fig. 9—Equi-hardness lines of 1.0% Carbon Steel Quenched in Water from 870 Degrees Cent.

other. In the outer portion, where cooling is very rapid, not only the second change of the A_1 transformation, martensite to pearlite, is stopped, but also its first change, austenite to martensite, is partially arrested so that this portion contains a certain amount of austenite intermingled with martensite. In the inner portion, the rate of cooling is not so rapid, and hence the austenite is mostly transformed into martensite; but its further transformation into pearlite is arrested. Since the austenitic structure is much softer than the martensitic structure, it is to be expected that the outer portion.

containing a greater proportion of austenite than the inner portion, will be softer than this portion.

If the above view be correct, for a soft quenching, such as quenching in oil from a moderately high temperature, the outer portion may be just fully martensitized, while in the inner por-

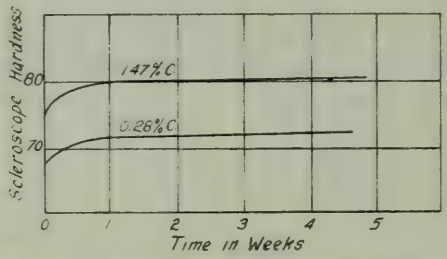

Fig. 10—Showing that a Hard Quenched Specimen at Room Temperature will increase in Hardness with Lapse of Time. Quenched in Water from 880 Degrees Cent.

tion, the transformation from martensite to pearlite is partial. In this case, the outer portion must be harder than the inner portion, as is actually brought out by experiments. In a somewhat harder quenching than in the last case, the outer and inner portions may possess nearly the same hardness. The fact that above 820 degrees

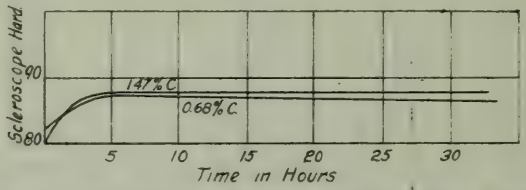

Fig. 11—Showing that Quenched Specimen when Constantly Heated at 100 Degrees Cent. will first Increase in Hardness and then Slightly Decrease. Specimen Quenched in Water at 880 Degrees Cent.

Cent. the hardness gradually decreases as the quenching temperature increases, is explained by the same theory, that is, by a gradual increase of austenite arrested and mixed in martensite.

Several quenched specimens were examined microscopically to see whether any appreciable decarburization actually occurred; but except narrow edges, or at least in portions where hardness was measured, decarburization was negligibly small. Hence the less hardening of the outer portions cannot be explained by decarburization during heating. In many cases, however, it is caused by the arrested austenite during quenching.

The cause of cracking was next investigated in a series of equi-hardness curves for a number of carbon steels quenched from varying temperatures. Since the form of the equi-hardness lines was elongated in the direction perpendicular to the line of cracking (Fig. 7), it is to be concluded that the martensite development is greatest in the elongated central portion and least in the periphery: hence the martensitic expansion in the former portion is much greater than that in the latter portion. The central portion exerts, therefore, a great tension on both sides, this tension causing the cracking of the specimens. This is the reason that the lines of cracking are normal to the elongated equi-hardness curves. Since the difference in the specific volumes for martensitic and austenitic structures increases rapidly as the temperature falls[12], it may be understood why cracking generally occurs, when the temperature of the specimen approaches to room temperature.

Conclusions

Having thus far explained the distribution of hardness and crack lines, the question of how to avoid quenching cracks arises. In quenching practice, it is not necessary to get a very great hardness, except in the case of cutlery. It is also evident from the above investigation that to obtain a martensitic structure, too rapid cooling is unnecessary. In order, therefore, that the specimen may not crack during quenching, but that its hardness be properly developed, quenching must be medium hard, such as quenching in oil from 900 degrees Cent. (1650 degrees Fahr.), in which case the hardness is nearly constant throughout the specimen; hence the stress due to the difference in the structures is small, and consequently cracking cannot occur.

According to the above view, in a hard quenched steel, some austenite remains untransformed at room temperature, at which this austenite will slowly transform into martensite. On the other hand, at room temperature martensite has a tendency further to be transformed into troostite, but its velocity is much smaller than that of austenite→martensite just referred to. The consequence is that at room temperature a hard quenched specimen will slowly

12. K. Honda, *Science Reports* 8, (1919), 186

increase its hardness with lapse of time. This inference is brought out by experiments[13] (Fig. 10).

If the quenched specimen be constantly heated at 100 degrees Cent. instead of letting it remain at room temperature, the above change from austenite to martensite will be much accelerated, at the same time the change from martensite to troostite will also be accelerated. Hence the hardness first increases, reaches a maximum, and then slightly decreases. As shown in Fig. 11, this conclusion is actually brought out by experiments[14].

13. 14. *Science Reports* 9, (1920).

METALLOGRAPHY AND TESTING OF OXYACETYLENE WELDS

By J. R. Dawson

Abstract

This paper deals with the application of oxyacetylene welding to various classes of steel and to cast iron. Photographs are included to illustrate the effect of the process on the structure of metals that are welded. The physical properties of welded metals are discussed and illustrated by typical test results.

The author has emphasized that oxyacetylene welds are quite dependable when the work is done under suitable conditions and with proper supervision. Stress has been laid on the need for testing of the welder's work. The opportunities for saving, that results from greater use of the welding have been mentioned, and a plea made for the application of the principles of heat treating to welding problems, which are of a nature to require metallurgical knowledge.

WELDING is a metallurgical operation. Since we, as steel treaters who devote our experience and thought to proper control of metallurgical practice and correct heat treatment methods, are frequently called upon to decide the suitability of welding applications to production work and repairs of products or plant maintenance, the author ventures to present briefly, results and conclusions arrived at in the course of extensive research in the problems of oxyacetylene welding and cutting.

The extent of the metallurgical features of oxyacetylene welding may well be appreciated from the consideration that molten metal under the gas flame is comparable to the bath of an open-hearth furnace, and is subject to treatments similar to those given the open-hearth bath, such as changes of composition due to oxidation, addition of alloys, and interchange of elements be-

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tween the metal and slag. Furthermore, metal adjacent to the zone of deposited metal is necessarily heat treated to some extent, and throughout all investigations of welds and welding this heat-treatment factor is of importance.

Importance of Competent Welders

The results obtained in fusion welding are quite uniform and dependable when suitable materials are used and the work done by competent welders. The most important element affecting weld quality, is the manner in which the operator handles the work. The following factors are also of importance in securing satisfactory quality of welding:

1. *Selection of men*

Most men of average ability can become good welders. The requirements are honesty, patience, and a reasonable amount of manual dexterity.

2. *Training methods*

Training is obviously of the same importance for this work as for that of other crafts. Mention should be made at this point of the excellent work of the American Welding society committee on training operators.[1]

3. *Supervision*

Those in charge of welding work should understand the properties of the metals being handled and of the welded article, and they should know enough of the details of correct welding methods to judge the quality of the work being done.

To prove the quality of a welder's output, it is only necessary to use the tensile or bend test on a number of specimens made by him, welding materials of satisfactory quality, having been provided. Check-tests of welder's work are of great importance and should be made regularly by competent supervisors who are capable of recognizing the quality of welding.

Until recently, little distinction was made between welding rods and ordinary wire, but the need of suitable, good quality rods, is of first importance, for the quality of the resulting deposited metal is largely dependent upon the rod used.

1. Bulletin of the American Welding Society, May, 1923.

Quality of Welding Rods

Fig. 1 shows welding rod steel that is practically free from nonmetallic inclusions. Fig. 2 is of welding rod steel that is unsatisfactory on account of the large number of nonmetallic inclusions. When the dark areas are examined at higher magnification they are seen to contain small slag particles. Welding rods of quality illustrated by Fig. 2 are quite common but the better quality material can be made and tons of welding rods of high purity are consumed every month. Flame melting tests have been

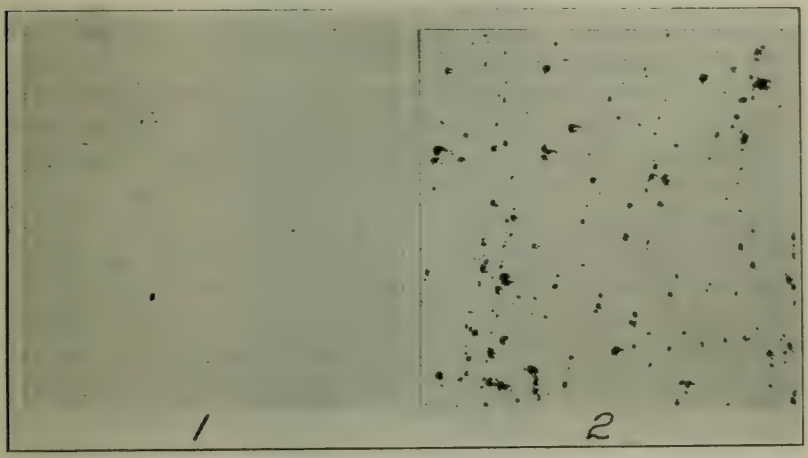

Fig. 1—Photomicrograph of a Polished but Unetched, Good Quality Welding Rod, x100. Fig. 2—Photomicrograph of a Polished but Unetched, Poor Quality Welding Rod, x100.

devised that will discover the steel containing nonmetallic inclusions and dissolved or occluded gases. One such test that is often applied, is to place the welding rod in a horizontal position and pass a welding flame of suitable size over its length at such uniform rate as to melt half way through the rod. It should melt and flow together evenly without boiling or throwing off sparks. If the steel contains gases the metal upon solidifying will be of spongy appearance. The 'dirt' contained in the steel can be observed during the melting, as it reflects more light than the metal and appears as brilliant white spots or lines. When such inferior

rods are used it is difficult to prevent the inclusion of impurities and gas pockets in the weld.

Low-Carbon Steel Welding

At present most steel welds are made with rods of the following composition:[2]

Carbon—Not over	0.06 of one per cent
Manganese—Not over	0.15 of one per cent
Silicon—Not over	0.08 of one per cent
Sulphur—Not over	0.04 of one per cent
Phosphorus—Not over	0.04 of one per cent

Rods of other compositions are also available and some of them will be described later in this paper.

The tensile strength of a double V weld, properly made in ½-inch plate with a low-carbon steel rod is about 52,000 pounds per square inch, but experience has shown that without knowledge, care and skill, a weld of this strength will not be obtained. It is quite necessary that sample welds be tested, because many welding operators permit imperfections in their work and do not know it. A simple test is to place a specimen in a vise with the center of the weld at the top edge of the jaws and to hammer until fracture occurs. Inspection of the fracture will reveal the nature of any defects and by practice and repeated tests the faults may be overcome. The ability of each welder should be tested in this way, or better, by pulling the welds in a testing machine, before he is permitted to do important work. Occasional tests should be required to prove that a proper standard of efficiency is being maintained. This point may be illustrated by results recorded in Table 1, of a series of tests of welds made on consecutive days.

This example is entirely typical of a welder with considerable experience, unknowingly doing poor work and making almost 100 per cent improvement once his mistakes are demonstrated.

A series of experiments were recently carried out to determine the physical properties of weld metal. Blocks of metal were deposited so that test specimens about 4x⅜x1½ inches could be machined out, and the results as shown in Table II were ob-

2. Welding Wire Specifications and Folios, American Welding Society, Bulletin No. 2.

Fig. 3—Macrograph of Double "V" Weld in ⅝ Inch Low-Carbon Steel Plate, Etched with Ammonium Persulphate, ×3

tained in testing the untreated material.

In this table the results for tensile strength compare favorably with those obtained in testing annealed low-carbon steel, but the elongation and reduction of area are not so good as in rolled plate. It is of interest to note that in tests of welds made in

Table I

Tensile Tests of Single "V" Welds
Each Value is the Average for 5 Tests

Day Welded	Ultimate Tensile Strength Pounds per Square Inch	Elongation Per Cent In 2 Inches
1st	27,000, equivalent to strength obtained by single riveting	3.2
2nd	37,500	6.5
3rd	43,200	12.4
4th	46,100, equivalent to strength obtained by triple riveting	11.5

similar materials with a given type of rod, that elongation and reduction of area vary with the tensile strength while in rolled material one usually increases as the other becomes less.

In Fig. 3 the darker material near the center is filled-in weld metal whose grains are relatively coarse. The structure of the base metal adjacent to the weld has been coarsened by the high

Table II

Tensile Tests of Weld Metal Deposited with Oxyactelylene Flame

Specimen Number	Size	Pounds Per Square Inch Yield Point	Tensile Strength	Elongation Per Cent In 2 Inches	Per Cent Red of Area
1	1.483 x .366	36,000	49,100	29.0	26.9
2	1.503 x .386	32,300	53,500	36.0	41.0
3	1.507 x .381	37,000	50,800	32.0	35.9
Average		35,100	51,100	32.0	34.6

temperature attained at that point. It may be observed that the structure of a portion of the weld metal and surrounding base metal has been refined when the second side was welded. At a distance from the weld of about 3 times the base metal thickness, a temperature has been reached which was just high enough to refine the base metal grains. This is the point of greatest ductility and of lowest strength of base metal. Tensile test specimens often break in this zone.

Fig. 4 shows the structure of low carbon steel weld metal.

This material is similar in structure to a steel casting, and is practically carbonless. The scattered small black dots throughout the area are believed to be ferrous oxide.

Experiments have been made in annealing low carbon steel welds, in which it was found that a temperature of 1750 degrees

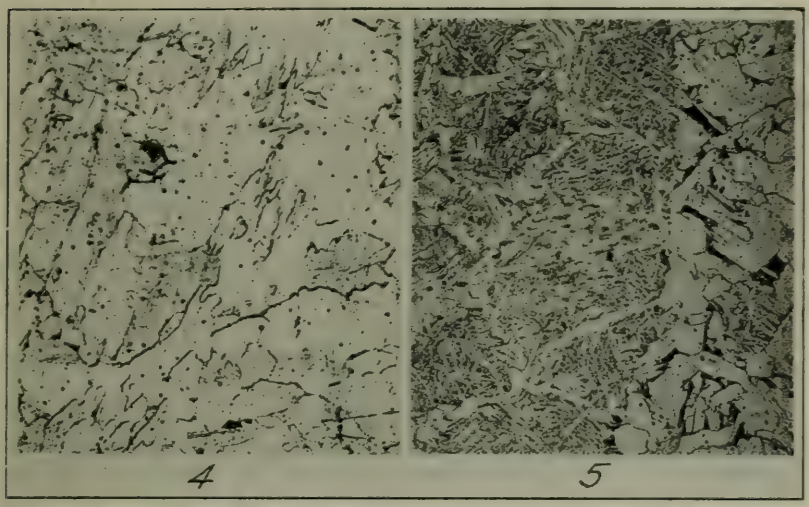

Fig. 4—Structure of a Low Carbon Steel Weld Metal. This Material is similar in Structure to a Steel Casting and is Practically Carbonless. The Small Black Spots are Believed to be Ferrous Oxide, x100. Fig. 5—Structure at Junction of Nickel Steel Weld Metal, at Left, and Coarsened Low Carbon Steel Parent Metal, at Right. This Lacy Structure is Characteristic of a Nickel Steel Weld Metal, x100.

Fahr. was required to refine the grains. This high temperature coarsens the base metal and to obtain good structure throughout the section a second annealing at 1450 degrees Fahr. is required. Annealing does not increase the weld strength but does make some improvement in ductility.

An outstanding feature of recent development in low carbon steel welding is the success attained in welding steel and wrought iron pipe. Until rather recently only a limited amount of steam, oil, gas, and water carrying pipes were welded. Studies have shown that the welding is not only less expensive than other methods of installation in first cost, but that it has a tremendous advantage due to the avoidance of leakage with its attendant loss of product and expense for repair and damage. Because the

screw joint weakens the pipe at the thread, and flanges or caulked joints are loosened by strains or vibration, it is not unusual to have a loss of 10 to 20 per cent of fuel gas or illuminating gas by leakage from lines having such joints. Leaking gas always brings to mind the hazard of carbon-monoxide poisoning. Welded oil carrying lines do not require frequent inspection, and so the need for line walkers is largely eliminated.

The advantages of these pipe welding applications have led to welding of high pressure steam lines and success has attended the

Table III

Chemical Analysis of Rods and Welds

	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon	Per Cent Nickel
Low Carbon Steel Rod	0.07	0.15	.007	
Weld made with it	0.05	0.10	.004	
Medium carbon steel rod	0.24	0.41	.043	
Weld made with it	0.08	0.32	.004	
Nickel steel rod	0.24	0.62	0.21	3.11
Weld made with it	0.12	0.36	0.03	2.83

efforts. The basis of this success was the testing of work done by the welders. Before a recent installation of a 21-inch welded steam line to carry 165 pounds pressure, the operators were required to weld around a joint which was later tested by cutting in strips across the weld and breaking it in the tensile machine. A surprising result of this test was that the specimens from the bottom of the pipe where overhead welding was required, were better than from other parts of the pipe. The explanation for this is that a relatively small flame must be used for overhead welding and better opportunity was given for careful work and the avoidance of overheating.

Medium Carbon Steel

It is sometimes recommended to weld medium carbon steel with medium carbon steel welding rods but tests as to strength of weld have shown no advantage over welds made with low carbon rods. As illustrated by Table III, the weld metals obtained from the two rods are of practically the same chemical composition.

The loss of carbon is less with the nickel steel and a stronger weld is obtained when it is used. Fig. 5 illustrates the structure

at the junction of nickel steel weld metal, at the left, and the coarsened low carbon steel parent metal, at the right. This lacy structure is characteristic of a nickel steel weld metal. The junction of two types of structure affords an excellent opportunity to observe the method of intermingling of the two metals by the growth of grains across the boundary.

An objection sometimes aimed at welding is: "Well, the tensile strength is all right but the elongation and contraction are low. What will happen when the weld is subjected to bending and alternating stresses?" The average tensile strength of a well made low carbon steel weld is 52,000 pounds per square inch and the average reinforcement is 20 per cent of the plate thickness, so that the available strength of the joint is 60,000 pounds per square inch of plate section. Most low carbon steels are of less strength. If greater weld strength is desired rods of special composition will produce a weld of 58,000 to 60,000 pounds per square inch of plate, and reinforcement will still further increase this figure to about 70,000 pounds per square inch as referred to base metal thickness. Inherently and by reason of the reinforcement, the weld is also stiffer than the plate metal, so that bending stresses are resisted by the weld and bending occurs in the adjoining metal as illustrated in Fig. 6.

These are single "V" welds in ½ inch low carbon steel plate with the standard low carbon steel welding rod. These 1½ inch wide strips were cut from the welded material and bent at the weld by holding in a vise and striking with a sledge hammer. When this bending was carried as far as possible the specimens were brought to the form shown by steam hammer blows. At first, most of the bending was outside the weld but in this case the heavy blows forced the weld to bend to about a ½-inch radius. In a recent valuable paper [3] describing extensive investigations of endurance properties, it was pointed out that endurance properties are definitely related to tensile strength and that for many uses too much importance has been given to ductility. Increase of tensile strength increases the resistance to fatigue failure. Since the weld can and should be made of greater strength than the metals joined, high resistance is offered to alternating and

3. D. J. McAdam, Jr., American Society for Testing Materials, *Proceedings*, 1923, entitled "Endurance Properties of Steel: Their Relation to Other Physical Properties and to Chemical Composition."

other stresses and should the use require ductility it will be obtained from the material surrounding the weld.

As has many times been pointed out, a weld is only a casting, but there are certain differences from most castings. The weld metal is molten only an instant. Time is given for impurities to float to the surface, and then the blowpipe is advanced and the

Fig. 6—Bending Tests of Welds, Actual Size.

metal freezes. The volume of melted metal is so small that solidification occurs before extensive dendritic structures have had time to form, and therefore some of the objectionable features that are associated with steel castings are not encountered in welds.

Those engaged in the art of heat treating are familiar with the effects of sonims and other imperfections on the quality of the steel they use. The welding engineer is also deeply concerned with the problem. The quality of base metal has a decided influence on the weld obtained. There is a certain amount of intermingling of the base metal and filling rod metal, as both are melted together to form the weld. If slag particles of the base metal are numerous there is a tendency for films of oxide to be formed

around the grain boundaries at the junction of weld and base metal, and also at times lines of oxides are found deposited in the high temperature ferrite grain boundaries of the base metal adjacent to the weld but not melted during welding. This oxide was no doubt dissolved by the metal when at high temperature and rejected to the grain boundaries during cooling. Steel containing gases is especially objectionable when used in the form of sheet metal for welding. Porosities are formed by gases that escape during solidification of the melted steel.

Steel Forgings

It is impossible to formulate rules for welding of steel forgings that will be of general application. The following must be considered:

1. The chemical composition
2. The stresses the metal at the weld must endure
3. Possibility of heat treatment

It should be kept in mind that the metal near the weld is heated and the extent of the effect depends upon the temperature attained and the length of time at that temperature. This heating may create a structure less desirable than the original and will certainly produce a difference between the structures of the weld and surrounding metal, and the remainder of the forging. If the weld is required at a point where only small stresses will be applied to the part in service, welding of course is permissible. If suitable heat treatment can be economically applied to the welded forging structural uniformity will be regained.

A use of the oxyacetylene process that is becoming of increasing importance is the cutting of steel forgings, by which, in a wide variety of instances great savings are made by reduction of the amount of machining necessary to complete the part.

Fig. 7 is a macrograph of section of a forging 5 inches thick after cutting with the oxyacteylene cutting blowpipe. The structure of the darkened area on upper side of picture, has been altered by the heat incident to cutting. This area is less than 3/16 inches in depth. Further investigation of this material shows that annealing removes the difference of structure. Researches have

developed the following information:

1. Steel containing less than 0.40 per cent carbon can be cut accurately and smoothly without difficulties of any sort, and with great saving of time and expense.
2. Preheating to about 800 degrees Fahr. is advisable when the carbon content is above 0.40 per cent, for if the steel happens to be of poor quality small cracks may occur unless this precaution is taken.

High Carbon Steel

As the carbon content of steel becomes greater the metal is more easily overheated with attendant difficulty in obtaining high

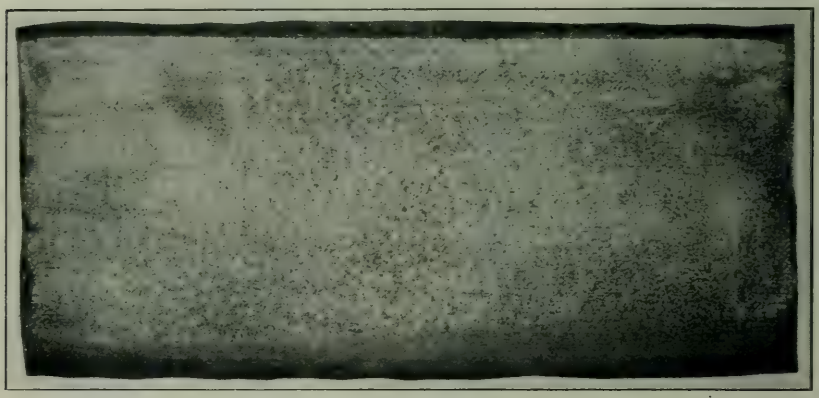

Fig. 7—Steel Forging Cut by Oxy-acetylene Blowpipe, taken at nearly Full Size. The Structure of the Darkened Area on Upper Side has been Altered by the Heat Incident to Cutting.

strength welds. A capable welder will not 'burn' steel containing 0.90 per cent or less carbon. Fig. 8 shows the structure of a 1.10 per cent carbon steel that has been welded. The 'burnt' area shown was on the bottom side near the weld. The black lines at the grain boundaries show the burning. They are really cracks. The top of the specimen was enveloped by the welding flame and protected from oxidation.

An important welding application to the higher carbon steels is filling up to original form of areas that have been worn. By correct selection of welding rod, the repaired portion is frequently made more resistant to wear than the original metal.

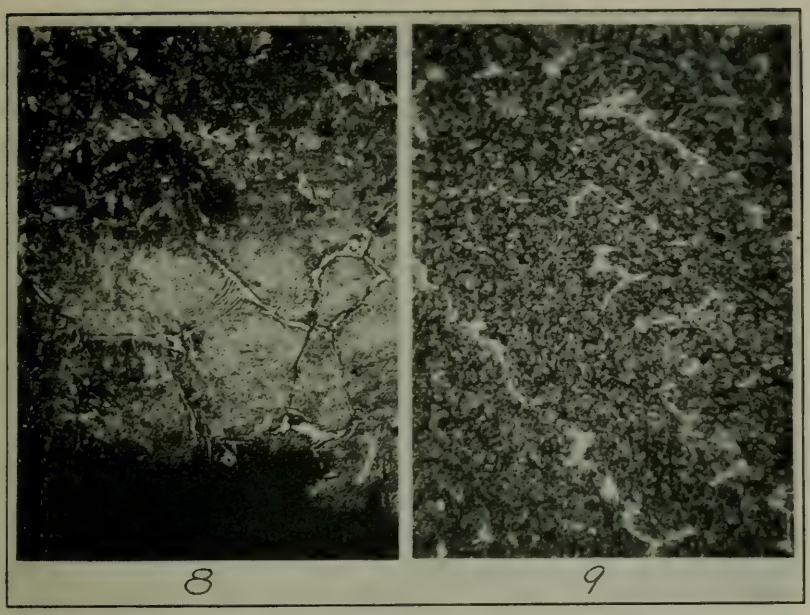

Fig. 8—"Burnt" High Carbon Steel, Near Weld. The Burnt Area Shown at the Bottom of the Photomicrograph, x100. Fig. 9—Welded High-Speed Steel Tool Tip, x435. Most of the Carbide Particles are Small and Widely Distributed.

From the standpoint of welding, alloy steel may be classed with forgings. There are many instances where the process may be used to advantage and others where it would be a mistake to employ it. The use of the steel part, its composition, adaptability to heat treatment, the point at which welding is applied, etc., all have a bearing on the decision of suitability for welding. In many cases a rod of the same composition as the steel to be welded may be used to advantage.

High-Speed Steel

It is sometimes practicable to make special high-speed tools by the oxyacetylene welding process. Where extra strength of tool is required or a type of tool that is used only occasionally is needed, a mild steel shank may be machined out at the end, a carborundum mold placed around it and high-speed steel rod of usual composition melted in by the blowpipe. Such a tool may be

forged, quenched and tempered.

Fig. 9 shows the structure of the metal in a welded high-speed tool tip. Most of the carbide particles are quite small and widely distributed. The ground mass appears to be troostite. Traces of austenitic grain boundaries obtained in hardening still remain in the tempered tool.

Manganese Steel

So far as is generally known, welding of manganese steel has never been thoroughly investigated. The following photomicrographs will serve to give an idea of what occurs when welding is done. Fig. 10 shows the structure of weld metal obtained. It is made up of large grains of dendritic form. The structure shown in Fig. 11 is of the base metal 1/8 inch from the weld. The heating of the metal has caused marked grain growth to occur. Fig. 12 is of same location as Fig. 11, but at higher magnification. The grains are of martensitic appearance. Thin films of iron or manganese carbide can be seen between some of the grains. Fig. 13 shows the structure of the weld metal. Grains that appear to be martensite are surrounded by carbide films, and splotches of carbide are scattered throughout the section. Fig. 14 is of weld metal after heating to 1050 degrees Cent. and quenching in water. Carbides are absorbed, large grains have been broken up and much of dendritic structure removed.

The valuable properties of manganese steel are developed by quenching from a high temperature which produces an austenitic structure in which the grains should not be large. The austenitic manganese steel is easily converted to a martensitic condition. Relatively slight cold work as in the passage of locomotive and car wheels over a manganese steel frog will harden the stressed surface and not affect the remainder of the material. As the surface wears away new metal is stressed and hardened. The body of the metal then is strong and tough and wearing surface hard. It is also more susceptible to heat treatment than other steels. This is illustrated by the rapidity of grain growth, and the ease of formation of martensite and carbides.

Welds made in 3/8 inch thick manganese steel with manganese steel rods containing 1.25 per cent carbon and 13.00 per cent

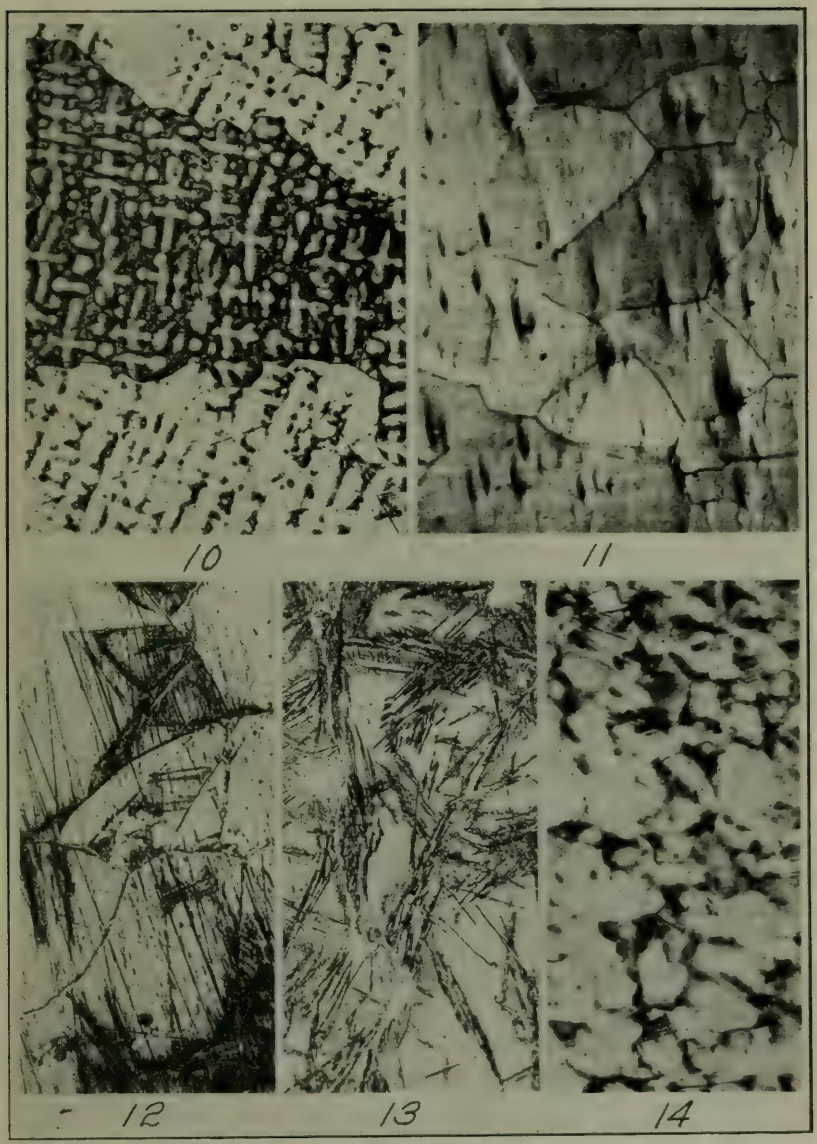

Fig. 10—Manganese Steel Weld Metal, x100, Showing Dendritic Formation. Fig. 11—Manganese Steel Base Metal, Near Weld, x50. The Heating of the Metal has Caused a Marked Grain Growth. Fig. 12—Same as Fig. 11 at, x425. The Grains are of Martensitic Appearance. Fig. 13—Manganese Steel Weld Metal, x425. Grains Appear to be Martensitic Surrounded by Carbide Films. Fig. 14—Heat Treated Manganese Steel Weld Metal, x50. Quenched in Water from 1050 Degrees Cent.

manganese, were tested by clamping in a vise and bending by hammering. The results recorded in Table IV were obtained.

These foregoing tests and photomicrographs indicate that where strength and resistance to shocks are required, the entire weld containing article of manganese steel should be heated to 1050 degrees Cent. and quenched in water. Evidently 1000 degrees

Table IV
Bend Tests of Welded Manganese Steel

Test	Kind of Flame	Heat Treatment	Angle of Bend Before fracture
1	Excess Acetylene	As welded	Zero degrees
2	Neutral	As welded	25 degrees
3	Neutral	One-half hour at 1000 degrees Cent. Quenched in water at room temperature	75 degrees
4	Neutral	Same as 3. Then ½-hour at 1050 degrees Cent., again quench in water at room temperature	95 degrees

Cent. is not high enough temperature for best results. Molten manganese steel absorbs carbon very readily and the elimination of carbides and formation of austenite become more difficult as the carbon content increases. It is the practice of many welders to use an excess acetylene flame for manganese steel welding, but the neutral flame is preferable. The analyses shown in Table V in-

Table V
Manganese Steel Analyses

Kind of Flame	Material	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon
Neutral	Welding rod	1.10	11.50	.08
	Weld metal obtained	1.00	9.60	.05
Excess acetylene	Welding rod	1.17	15.62	0.52
	Weld metal obtained	1.52	13.48	0.21

dicate the effect of welding on the composition of manganese steel.

Since the best properties of manganese steel are not obtained with less than 11.00 per cent manganese the rod should contain not less than 13.00 per cent manganese to compensate for the 2 per cent that is lost during the welding operation.

The addition by welding of manganese steel to other steels

is not satisfactory, for at the weld junction there is diffusion between the weld metal and the base metal and a gradient of manganese content from about 11 per cent to less than 1 per cent will be formed. Some of this junction zone will be weak and brittle, regardless of the treatment applied. For satisfactory results in welding manganese steel, the following should be kept in mind:

1. A neutral welding flame should be used.
2. Welding rod should contain at least 13.00 per cent manganese.
3. The entire welded part should be quenched from 1050 degrees Cent. in water, in cases where service requires high strength and resistance to shocks. Where service requires only compressive strength or resistance to wear, heat treatment is unnecessary.
4. Red hot manganese steel is very brittle and articles during welding should be supported in such a manner as to avoid setting up strains that might cause cracking.

Cast Iron

One of the important applications of oxyacetylene welding is the repair of cast iron parts. The principal reasons for the wide use of this method are:

1. The joint obtained is of high quality.
2. The weld and adjoining metal are machinable.
3. The welding repair, in addition to costing much less than a new casting, is usually important because of the time saved. Frequently a weld can be made and the broken part placed in operation in a fraction of the time required to secure a new part. Many foundries are enabled to hold to high rate of production and efficiency of operation because of the aid of oxyacetylene welding in reclaiming defective castings. This is a practice which should be highly recommended because quality of welded castings is satisfactory and the operation is without harmful effects.

The macrograph shown in Fig. 15 is of a weld in gray iron. There are no blowholes or oxide films, and the weld metal is less coarse than the original metal. Transverse tests of numerous

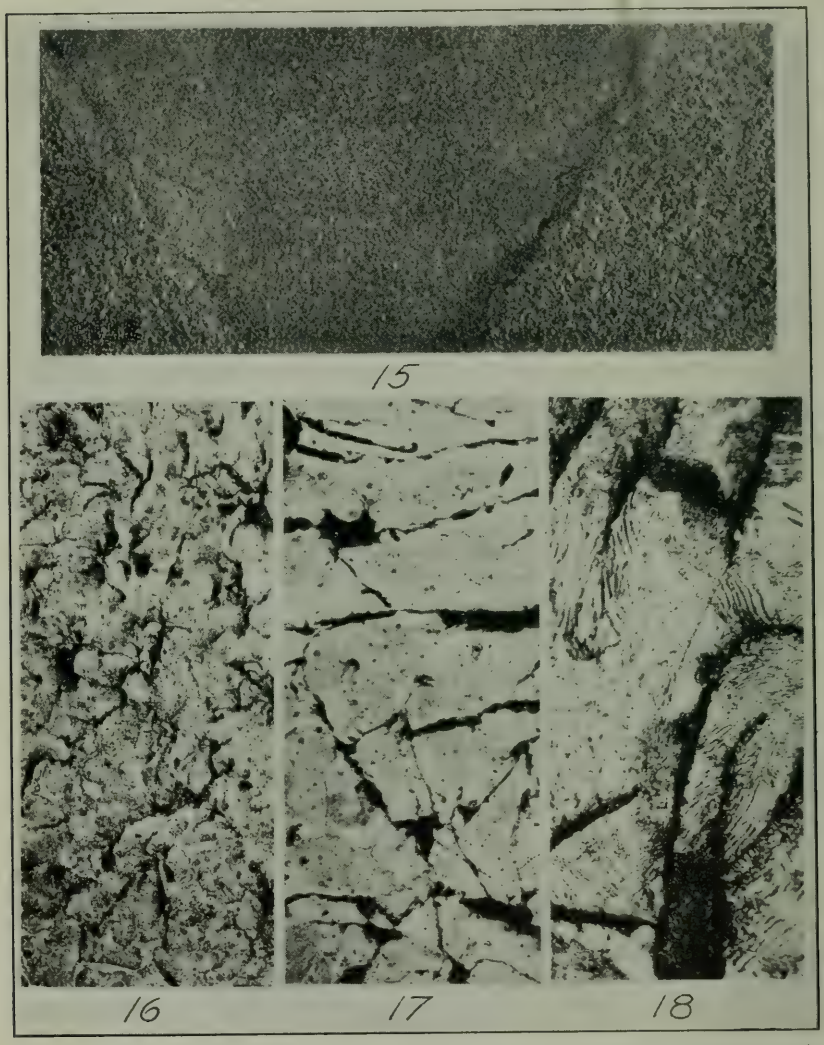

Fig. 15—Weld in Gray Iron, x2. Etched with Copper Ammonium Chloride. Fig. 16—Photomicrograph of Gray Iron Weld Metal, x100. Fig. 17—Photomicrograph of Gray Iron Casting, x100. Fig. 18—Photomicrograph of Gray Iron Weld Metal, x425, Showing Graphite, Lamellar Pearlite and Ferrite, There Being No Free Cementite.

cast iron welds show that it is difficult to cause the break to pass through the weld, which proves that the weld is stronger than the original metal.

The reason for greater strength in the weld may be explained by reference to Figs. 16 and 17. The graphite in the original metal is in the form of large plates or flakes which weaken and embrittle the cast iron. The graphite in the weld is of smaller amount and in smaller plates more rounded in form. The weld also contains a greater proportion of pearlite. Fig. 18 shows the weld metal structure in greater detail. It is made up of graphite, lamellar pearlite and ferrite, there being no free cementite.

The obtaining of good quality, machinable welds requires the use of knowledge gained perhaps in other phases of heat treatment. The hardness of carbon steels is profoundly affected by the rate of cooling and the same is true of cast iron. Provision must be made for slow cooling. Burying in lime or sand is an aid. If the weld is small and the part welded large, heat will be conducted rapidly away from the weld and chilling will occur and some preheating is frequently necessary to avoid this rapid cooling.

An important factor of successful cast iron welding is the employment of correct preheating. Where the parts are free to expand, preheating is unnecessary. Welding of a broken lug is an example of repair in which preheating is not required. Where the weld is surrounded by metal the expansion due to local heating will cause cracking. The same rules as apply in other heating should be employed. Heat slowly and uniformly, make the weld and cool very slowly. In some cases where the part contains sections of widely different area, welding should be followed by a second heating to a uniform temperature before cooling is begun.

Other important considerations are the use of correct welding rod and suitable flux. The influence of the various elements of gray iron composition are fairly well understood. To avoid hardness of weld metal, cast iron welding rods should be of high silicon content, and sulphur should be relatively low. Thus, graphite is precipitated rapidly and free cementite avoided. A proper flux combines with the slag, which is viscuous due to a high proportion of silicon oxide, and forms new slag that is thin, easily fusible, and readily floated to the surface of the weld. The cause of most blowholes in cast iron welds is the failure to float minute impurities to the surface. Careful microscopic examination

will show that where blowholes are permitted to form, a slag particle is the root of the evil.

Brazing of cast iron with manganese or Tobin bronze is meeting with increased favor. The advantages of this method are:

1. The parts can be joined at lower temperature than is required for welding with cast iron rods. Therefore brazing requires lower temperature preheating.
2. The joint obtained is stronger than the cast iron.

The methods of preparing cast iron for brazing are similar to the preparation for welding. Flux is used to clean the surface and when the cast iron is heated to a dull red color the braze can be made and a good junction obtained.

Various Welding Applications

White iron also can be satisfactorily welded. Welding rods of white iron composition should be used. Because of the brittleness of white iron, and its greater shrinkage than gray iron, even greater preheating precautions are required for white iron than for gray iron.

In addition to the uses to which reference has been made, oxyacetylene welding is successfully applied to the following metals: aluminum, copper, nickel and monel metal, and bronzes and brasses. Malleable iron should not be welded, but can be brazed successfully.

Conclusion

It has been the purpose of this paper to point out briefly some of the applications of welding and to emphasize the dependability of the process. A study of the rapid growth of welding and increase of its application leads one to the conclusion that the opportunities it offers for increased industrial efficiency are great.

A knowledge of metallurgy and heat treatment is necessary for proper understanding of the art, and members of this Society are especially fitted to appreciate the fundamentals of welding and its application to individual plants. It has been pointed out many times that actual loss results from failure to take advantage of the opportunities offered by this Society to aid in keeping pace with progress in heat treating knowledge and methods, and in the

same way it is unquestionably true that present day industries can ill afford to neglect the savings offered by modern welding methods.

Although it is true that heat treaters might well make greater use of welding, to an even greater degree the welding industries are in need of the interest and advice that you gentlemen are able to give, on account of your knowledge of the action of metals under high temperatures.

THE SEASONING OF STEEL

By W. P. Wood

Abstract

It is the custom of some manufacturers to age castings and forgings for a period of months in order to produce a more ductile metal. Speculation as to what other effects such a seasoning might produce in steel and iron lead to the test which is described in the paper. Briefly speaking, the experiment consisted in comparing the tensile properties of several varieties of unhardened steel before and after an exposure of one year to the varying temperature of the atmosphere. As might be expected, there was noted an increase in ductility and further than that, the alloy steels carrying noncarbide forming special elements such as nickel and silicon appeared to exhibit a decrease in tensile strength. The writer is not presenting this paper as a finished piece of work, but largely to ascertain through discussion or comment whether there is any unpublished data which may have a bearing upon the question in hand.

CONSIDERABLE interest has been evinced recently in what might be termed the low temperature phenomena of iron and steel. By this is meant any changes which take place in the metal after it has been cooled either rapidly or slowly to a temperature well below the familiar critical ranges. That many such changes do occur has been demonstrated by several investigators and this work was thoroughly summed up by Dr. Jeffries[1].

The writer would suggest that those interested in this matter, refer to Dr. Jeffries article as a starting point.

It has been a generally accepted opinion that these changes are the result of an attempt on the part of the metal to reach a state of equilibrium after heat treatment. The physical evidences of these changes include a gradual evolution of heat, dimensional changes, changes in physical properties, and so forth. It should

1. *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. LXVII, page 56.

A paper presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, W. P. Wood, is assistant professor of chemical engineering, University of Michigan, Ann Arbor, Michigan. Written discussion of this paper is invited.

be made clear that most of the changes have been noted in recently hardened steel rather than steel in the annealed condition.

It, however, would be hard to say just where this readjustment ceases, because we are limited by the delicacy of the means of measurement at our command.

The writer's interest was first aroused in this connection upon learning that it is the custom of some manufacturers to "season" iron and steel, particularly castings, before or after the final shaping and heat treatment. Probably the best example of seasoning is found in the manufacture of gauge blocks. Here, one of the absolute essentials is permanence of dimensions, and some form of seasoning is the only means which will bring this condition about in the metal. In general an artificial seasoning treatment involves alternate exposures of the metal to high and low temperatures within the range —10 to 212 degrees Fahr. H. J. French[2] has given a clear description of some seasoning treatments carried out at the U. S. Bureau of Standards. One striking thing about these treatments is the rather elaborate procedure and the length of time which is required to produce a state of rest in the steel. One point of interest which Mr. French mentions is the fact that the seasoning treatments do not affect all steels in the same degree. One also would infer from his results that permanence is more quickly secured in a steel carrying a high chromium content.

There seems to be no available data concerning the effect of seasoning upon all the physical properties of steel. Reinhardt and Cutler[3] found that the ductility of a steel carrying 0.49-0.55 per cent carbon was distinctly improved upon resting the heat treated steel at room temperature for various lengths of time subsequent to machining. Such a treatment constitutes a type of seasoning. Reinhardt and Cutler note a tendency to an increase of tensile strength while the ductility is increasing. This effect was not very marked however.

In order to satisfy his curiosity as to the effect of alternating temperatures over the range mentioned, upon some types of steel, the writer carried out the experiment which is reported in this paper. He has hesitated somewhat in presenting the results ob-

2. *Chemical and Metallurgical Engineering*, Vol. 25, No. 4, page 155.
3. *Bulletin*, American Institute of Mining and Metallurgical Engineers, No. 151, page 1091.

tained, for they seemed most peculiar and his main purpose in now presenting them is to ascertain through discussion and criticism whether or not there is any positive evidence which will settle the question one way or the other. If the physical tests had been made with less care the question would probably not be worth considering.

Procedure

Simply stated, the experiment consisted in making tensile tests upon several steels before and after an exposure of 1 year

Table I
Steels Used in Seasoning Test

Letter	Type of Steel	Analysis								
		Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Sulphur Per Cent	Phosphorus Per Cent	Chromium Per Cent	Nickel Per Cent	Vanadium Per Cent	Tungsten Per Cent
A	S.A.E. 1010	.05-.10		.30-.60	<.05	<.045				
R	S.A.E. 1080	.75-.85		.25-.50	<.05	<.04				
J	Nickel	0.29		0.55	0.035	0.04		3.48		
X	Chrome-Nickel	0.39	0.20	0.62	0.017	0.012	0.75	1.43		
F	Chrome-Vanadium	0.30					0.95		0.15	
S	Silico-Manganese	0.53	1.87	0.75	0.016	0.017				
T	High-Speed	0.65-0.70	0.2-0.3	0.2-0.3			2.90-3.10		0.95-1.05	17.50-18.50

to the varying temperatures of the atmosphere. The range of temperature variation was from about —10 to 100 degrees Fahr. The steels tested, with an indication of their analyses may be found in Table I. The steels used in this investigation were in the unhardened or "as received" condition. All samples were given a brief normalizing treatment to relieve strains. The relative conditions of the metal may be noted from the original tests in Table II.

The steel (which was 3/4-inch round bar stock) was cut into 7-inch lengths which were machined to the shape of standard test pieces. The diameter was left a trifle greater than the required 0.357 inch, the final finishing being done with a file after the normalizing treatment. In this way it was hoped that machining strains might be eliminated. Two of the finished specimens of each type of steel were pulled immediately and the rest were placed in shallow pans of cylinder oil which were located upon the roof of the chemistry building at the University of Michigan. The

pans of oil were covered by a wooden shelter which resembled somewhat an old fashioned chicken coop. By this means, water was prevented from directly entering the pans, but they were freely exposed to the atmosphere, and to the sun during a large part of the day. Enough samples were provided so that a few could

Table II

Results of Seasoning upon Physical Properties of Steel

Steel	Time of Test	Tensile Strength Pounds per Square Inch	Elongation Per Cent 1.4" gauge	Reduction of Area Per Cent
A	Original	48,950	40.0	
1010		50,000	35.8	67.2
	After 8 months	51,500	34.4	69.6
		51,000	36.0	68.2
R	Original	120,000	12.1	
1080		120,000	10.7	
	After 1 year	115,600	15.2	19.0
		118,400	12.0	19.0
J	Original	75,000	28.6	36.4
Nickel		76,000	27.9	35.0
	After 1 year	66,410	28.0	46.0
		65,820	30.4	46.0
X	Original	89,000	24.3	31.6
Cr-Nickel		90,000	22.2	31.5
	After 1 year	73,700	26.4	50.6
		68,195	28.0	52.9
F	Original	79,300	26.4	60.2
Cr-Va				
	After 1 year	79,000	36.0	63.6
S	Original	108,500	22.8	29.1
Si-Mn		108,500	22.8	30.3
	After 1 year	93,240	27.2	47.3
		99,450	23.2	39.5
T	Original	112,000	17.9	19.6
High-Speed				
	After 1 Year	101,800	17.6	24.1
		102,300	18.4	27.4

be pulled at intervals during the year, the last two being pulled one year from the day they were put into the oil.

The testing machine employed was a 100,000 pound universal. A gauge length of 1.4 inches was used in making tests.

Results and Discussion

In Table II may be found the results of the tests. The elastic limit was not determined at first because it was not thought that much change would be apparent in the tensile properties, since previous work had shown that the greatest change might be expected in the ductility. When it seemed after some months that

there were changes taking place in the tensile properties, the elastic limit was determined, but it was too late to make any systematic comparison.

As had been expected, a greater or less increase in ductility was observed, except in the case of the low carbon steel. Very little change of any nature was noted in this steel. The samples which were pulled at the end of a year broke prematurely owing to some flaw in the metal, and manifestly erroneous values were obtained. This test therefore did not extend beyond the eighth month interval. In the case of the 0.8 per cent carbon steel the original reduction of area was so slight that it could not be determined accurately, but after a year the ductility had increased to such an extent that the reduction of area had become 19 per cent.

The result which attracted most attention, was the apparent tendency on the part of some of the alloy steels to decrease in tensile strength. When a close comparison was made it was noted that the steels which tended to show the decrease in tensile strength were the 3½ per cent nickel, the chrome-nickel, the silico-manganese and the high-speed steel. With the exception of the high-speed steel, all these steels are of the type wherein the alloying elements are wholly or partially dissolved in the ferrite. The steels wherein there is the tendency to precipitate carbides did not seem to exhibit marked changes in tensile strength. The high-speed steel was an exception, but it is also true that this type of steel might show a variation from point to point in the original bar.

It would of course be absurd to attempt to develop an explanation of the peculiar behavior of the alloy steels until it had been proven beyond a doubt that the condition exists. It is the writer's intention to carry out another series of tests upon similar samples to obtain more complete information.

Leaving out of consideration the changes in tensile strength, the results of the seasoning upon the steel are what might be expected, namely, an increase in ductility, and the practice of allowing forgings and castings to rest out of doors for a period of several months in entirely justified in that the metal arrives closely at what might be termed a state of equilibrium. Dr. Langenberg[4]

4. *Bulletin*, American Institute of Mining and Metallurgical Engineers, No. 154, page 2935.

suggests that relief of strain is responsible for the increase of ductility but it would seem that there must be some constitutional changes also involved, particularly if tensile strength is affected.

Summary

The natural seasoning or aging of steel is justified in that the ductility of the metal is increased and a state of rest more nearly approached. There seems to be a difference with regard to changes in tensile properties in the behavior of the alloy steels when subjected to natural seasoning. The alloy steels which exhibited the greatest change during this test were those which carried one alloying element in solution in the ferrite.

The whole investigation has raised a question upon which there seems to be very little data, namely, what happens to the physical properties of various steels in service?

CASE HARDENING AND OTHER HEAT TREATMENTS, AS APPLIED TO GRAY CAST IRON

By H. B. Knowlton

Abstract

This paper describes certain experiments which were conducted in heat treating gray cast iron, after a report had been received that gray cast iron could sometimes be "case hardened" with commercial success. Some of the treatments used are similar to those used in case hardening steel. Several other schemes of heating and cooling were employed and are described. It was found that under certain conditions that gray cast iron could be made much tougher in the center and at the same time be given a hard surface.

SOMETIME ago the writer was informed that gray cast iron had been case hardened with commercial success. It was said that a certain firm had measurably increased the strength and wearing qualities of certain gray iron castings, by applying the treatments commonly used in case hardening steel. After this process, the castings were said to be fairly machinable in spite of their increased resistance to wear. The method was considered a success as long as it was applied to castings made by one foundry, but it failed on castings made in another foundry. Evidently the composition of the iron had a great deal to do with the success or failure of the method. The composition, however, of neither was known definitely. Both were simply classified as "gray iron."

The writer does not know how much has been done along this line, but so far has found nothing published on the subject. Consequently the research described in this paper was started. No claim is made that the paper is a complete exhaustive treatise on the subject. It merely attempts to give the status of the writer's research up to the present time. Criticisms, comment and suggestions are invited.

Upon casual consideration, case hardening of gray cast iron did not seem feasible to the writer, and yet it was claimed that

A paper presented before the annual convention of the Society, Pittsburgh, Oct. 8-12, 1923. The author, H. B. Knowlton, is instructor in metallography and heat treatment, Milwaukee Vocational school, Milwaukee. Written discussion of this paper is invited.

good results had been so produced. A gray cast iron obviously contains more carbon than can be retained in the combined condition. How then, could heating in a carburizing material increase the carbon content of the surface? The writer's only experience with cast iron heated in contact with a carburizing material, consisted in the use of cast iron pots and boxes used as containers in the carburizing process. It is a well known experience that such boxes "grow" on repeated and continued heating. This could be explained on the assumption that any combined carbon originally in the casting, decomposed into free graphite and free ferrite. The writer knew of no reason for assuming that carbon was combining with the iron during this process. Why then, were increased wearing qualities produced by "case hardening?" Was the function of the carburizing material simply to prevent oxidation? Did the quenching treatment merely harden whatever pearlitic areas there were in the original casting, or did some of the carbon in the casting or the carburizing material actually combine with the iron? Was the process similar to the production of chilled castings? If not, could any advantage be claimed for "case hardened" castings over the more common chilled castings? Would they have any advantages over malleable castings? These are some of the questions that the author has started to investigate.

Material

The experiments, herein described, were conducted on samples cut from three sand cast test bars of the following chemical composition.

	Bar No. 1	Bar No. 2	Bar No. 3
Silicon	2.12	2.41	2.49
Sulphur	.073	.073	.107
Manganese	.72	.59	.63
Phosphorus	.367	.635	

These bars were about 1 inch square and were cut into samples ¼ inch thick, with the exception of two samples, hereafter mentioned, which were 3/8 inch thick.

Each sample was given the number of the bar from which it was cut, and in addition was given an individual letter. Thus

samples 1A and 1B are the first and second samples respectively from bar No. 1.

First Series of Tests

Four samples each from bars 1 and 2 were packed in pipes with an ordinary carburizing material such as commonly used in case hardening steel. Two samples from each of these bars were packed in sand in another pipe. The ends of this pipe were protected from outside oxygen by thin layers of charcoal. All of the pipes were sealed with fire clay, placed in a hot furnace and run for three hours at 1700 degrees Fahr. At the conclusion of this heat they were given different treatments described in the data tables. Four other samples from each of these bars were heat treated in the open furnace as described in detail in the tables.

Second Test

After studying the results of these tests another series of tests were run. In this test, four samples from bar No. 3 were packed in a pipe with a carburizing material as before, and run for 8 hours at 1700 degrees Fahr. This pipe was placed horizontally in the furnace. Towards the end of the heat it was noted that the seal was leaking. This may explain some of the results mentioned later. Another sample from bar No. 3 was placed in the middle of a ball of fire clay, and heated in the open furnace for 3 hours at 1700 degrees Fahr. At the conclusion of this time it was allowed to cool slowly in the furnace.

Tests After Heat Treating

After heat treating, the specimens were all cleaned and tested under the Shore scleroscope. The Brinell method was tried on one or two, but it was found that the samples were too brittle for this test. All of them which could be cut with a hand hack saw were so sectioned. They are listed in the data tables as hard or soft on the basis of their ability to be cut with a hack saw. The specimens were placed one at a time in a vice and struck with a 3-pound hand hammer. This was given as a crude test of their toughness. All of the samples were polished and examined under the microscope both before and after etching with picric acid. One sample from each bar went through all of these tests in the

sand cast, untreated condition. The results are given in the data tables, and in the text following. Some of the more interesting microscopic structures were photographed and are shown herewith.

Results

Hardness

It will be noted that all specimens quenched from temperatures above 1500 degrees Fahr. were too hard to saw and showed a scleroscope reading above 55.

Toughness

The most startling thing about all the results was the extreme variation from great toughness to great brittleness on the different

Data Table I
Heat Treatments and Results on Samples from Bar No. 1

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
1A	Sand cast: no treatment	45	Soft	Brittle
1B	Carburized 3 hrs. cooled slowly	40	Soft	Brittle
1C	Carburized 3 hrs. cooled slowly; reheated to 1500°F; quenched in water	65	Hard	Fairly tough
1D	Carburized 3 hrs. quenched in oil directly	75	Hard	Brittle
1E	Carburized 3 hrs. quenched in oil; reheated to 1500°F; quenched in water	68	Hard	Brittle
1H	Heated 3 hrs. at 1700°F in sand; quenched in oil	62	Fairly Hard	Brittle
1I	Heated 3 hrs. at 1700°F in sand; quenched in water	62	Fairly Hard	Brittle
1J	Heated to 1700°F in open furnace; quenched in water	72	Hard	
1K	Heated to 1700°F in open furnace; quenched in oil	68	Hard	Brittle
1L	Heated to 1420°F in open furnace; quenched in water	47	Soft	Brittle
1M	Heated to 1500°F in open furnace; quenched in water	72	Hard	Brittle

specimens. The samples which were tested in the sand cast condition were all easily broken. Unfortunately there were no available means of making quantitative shock tests on specimens of this size. Simply testing by placing the specimen in a vice and hitting with a 3-pound hand hammer, is so crude that it is difficult to describe the results. Suffice it to say that the only ones which could be called tough at all were the ones which were heated in the carburizing

material, slowly cooled, reheated to 1500 degrees Fahr. and quenched in water. All of the specimens so treated showed some resistance to the hammer. The most startling variation was found between specimens 3C and 3G. Both of these were slabs 3/8 of an inch thick from the same bar. Specimen 3G was in the sand cast condition, while 3C had been carburized, cooled, reheated and quenched. The former was broken by one hard blow of the 3-pound hammer, while 3C could not be broken by numerous blows. A 3/32-inch

Data Table II
Heat Treatments and Results on Samples from Bar No. 2

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
2A	Sand cast; no treatment.	45	Soft	Brittle
2B	Carburized 3 hrs. cooled slowly...	39	Soft	Brittle
2C	Carburized 3 hrs. quenched in oil.	77	Hard	Brittle
2F	Carburized 3 hrs. quenched in oil reheated to 1500°F; quenched in water.....	63	Hard	Brittle
2G	Carburized 3 hrs. cooled slowly; reheated to 1500°F; quenched in water.....	55	Hard	Tough
2H	Heated 3 hrs. at 1700°F in sand; quenched in oil.....	55	Hard	Brittle
2I	Heated 3 hrs. at 1700°F in sand; quenched in water.....	55	Hard	Brittle
2J	Heated to 1700°F in open furnace; quenched in water.....	80	Hard	Brittle
2K	Heated to 1700°F in open furnace; quenched in oil.....	70	Hard	Brittle
2L	Heated to 1420°F in open furnace; quenched in water.....	47	Soft	Brittle
2M	Heated to 1500°F in open furnace; quenched in water.....	68	Hard	Brittle

V groove was then ground and filed in this sample, and it was again struck with the 3-pound hammer, but again it failed to break. After several attempts it was broken with a 10-pound sledge. The other samples which received the same heat treatment were only ¼ of an inch thick and consequently were easier broken. The specimens which were simply heated in the open furnace particularly to the higher temperatures, shattered quite easily when hit with a hammer. In some cases a light tap would cause the sample to break into several pieces.

Fractures

The fractures of the original castings were gray. Some of the

specimens quenched from the higher temperatures showed very light fractures which were very coarse grained. As already mentioned these were very brittle. The samples which were cooled slowly all showed gray fractures. Some of the specimens which were carburized, cooled, reheated and quenched showed a difference in the fracture between the center and the outer layer some-

Data Table III
Heat Treatment and Results on Samples from Bar No. 3

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
3A	Carburized 8 hrs. cooled slowly; reheated to 1500°F; quenched in water	70	Hard	Tough
3B	Carburized 8 hrs. cooled slowly	35	Soft	
3C	Carburized 8 hrs. cooled slowly; reheated to 1500°F; quenched in water	70	Hard	Very Tough
3D	Carburized 8 hrs. cooled slowly.			
3E	Sand cast; no treatment	45	Soft	Brittle
3G	Sand cast; no treatment			
3H	Heated for 3 hrs. at 1700°F in clay; cooled slowly	45	Soft	

Note—By the term "Carburized," used in these tables, and in connection, with the photographs, it is meant that the specimen so labelled was heated in a carburizing material to 1700°F, without regard to whether the process is true carburization or not.

what similar to the difference between the case and the core of a case hardened steel specimen. The difference was not so pronounced as in the case of steel. The fracture was not as light as some of the specimens quenched from the higher temperatures. Specimen 3C showed a very fine grayish fracture.

Microstructure

In order to understand better what changes actually took place the specimens were examined under the microscope. A few of them are shown here. While these speak pretty well for themselves, especial attention is directed to several things. Figs. 1, 2, 9, 10, 11, 17, 18 and 19 show the three bars in the original cast condition. It will be noted that the structure of each bar contains free graphite, free ferrite, and combined carbon in the form of pearlite. The specimens which were heated in the carburizing material and cooled slowly, show in each instance a

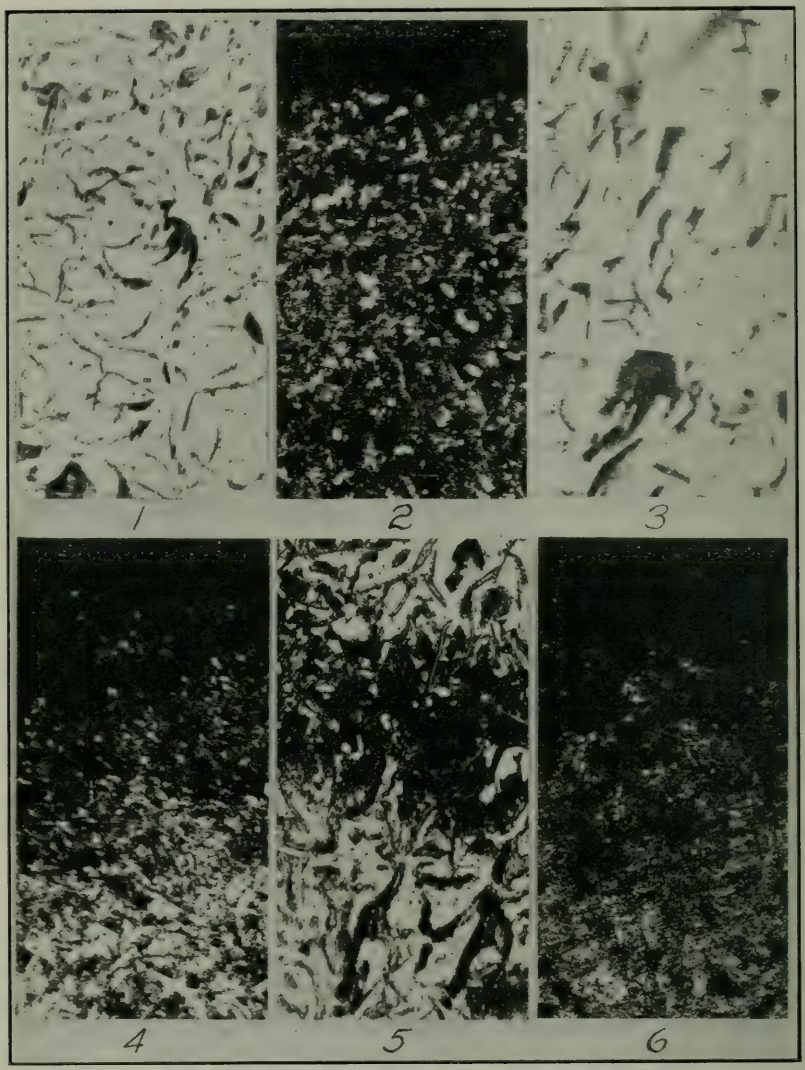

Fig. 1—Specimen 1A as cast, unetched. × 100. Fig. 2—Specimen 1A as cast, etched. × 100. Fig. 3—Specimen 1B, carburized, cooled, center unetched. × 100. Fig. 4—Specimen 1B, carburized, cooled, edge etched. × 100. Fig. 5—Specimen 1B, carburized, cooled, center etched. × 100. Fig. 6—Specimen 1C, carburized, cooled, reheated, quenched, edge etched. × 100.

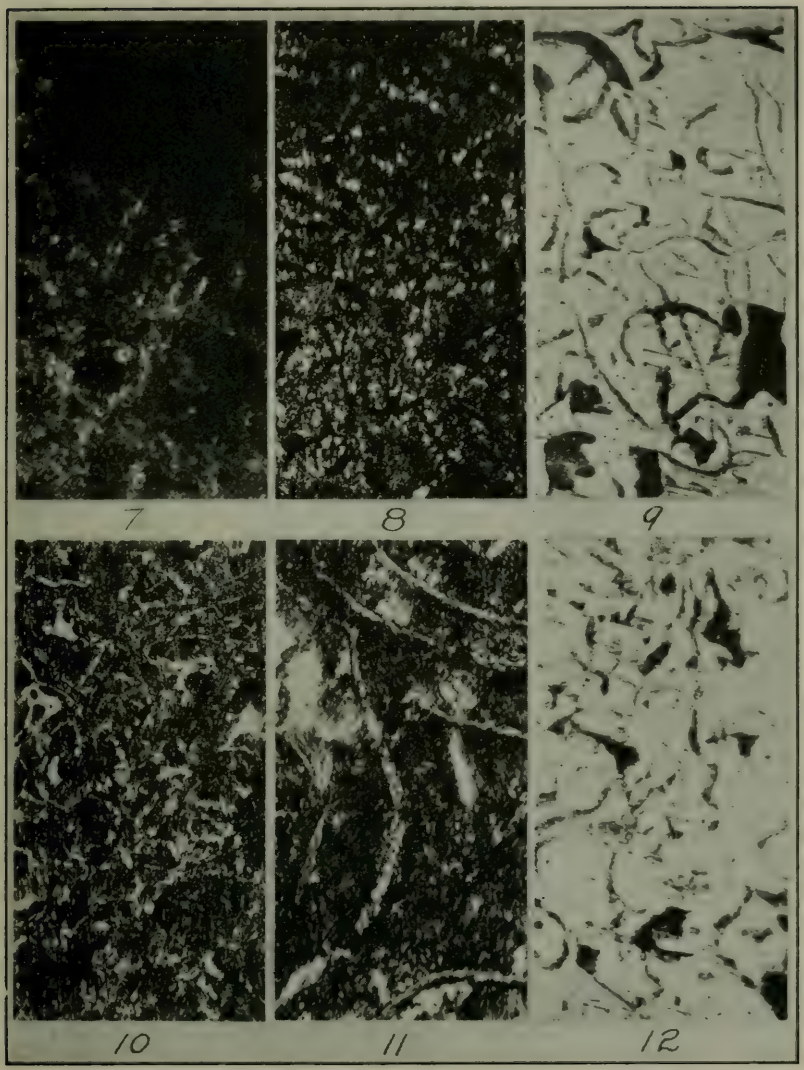

Fig. 7—Specimen 1C, carburized, cooled, reheated, quenched, edge etched. × 400. Fig. 8—Specimen 1C, carburized, cooled, reheated, quenched, center etched. × 100. Fig. 9—Specimen 2A as cast, unetched. × 100. Fig. 10—Specimen 2A as cast, etched. × 100. Fig. 11—Specimen 2A as cast, etched. × 400. Fig. 12—Specimen 2B, carburized, cooled, unetched. × 100.

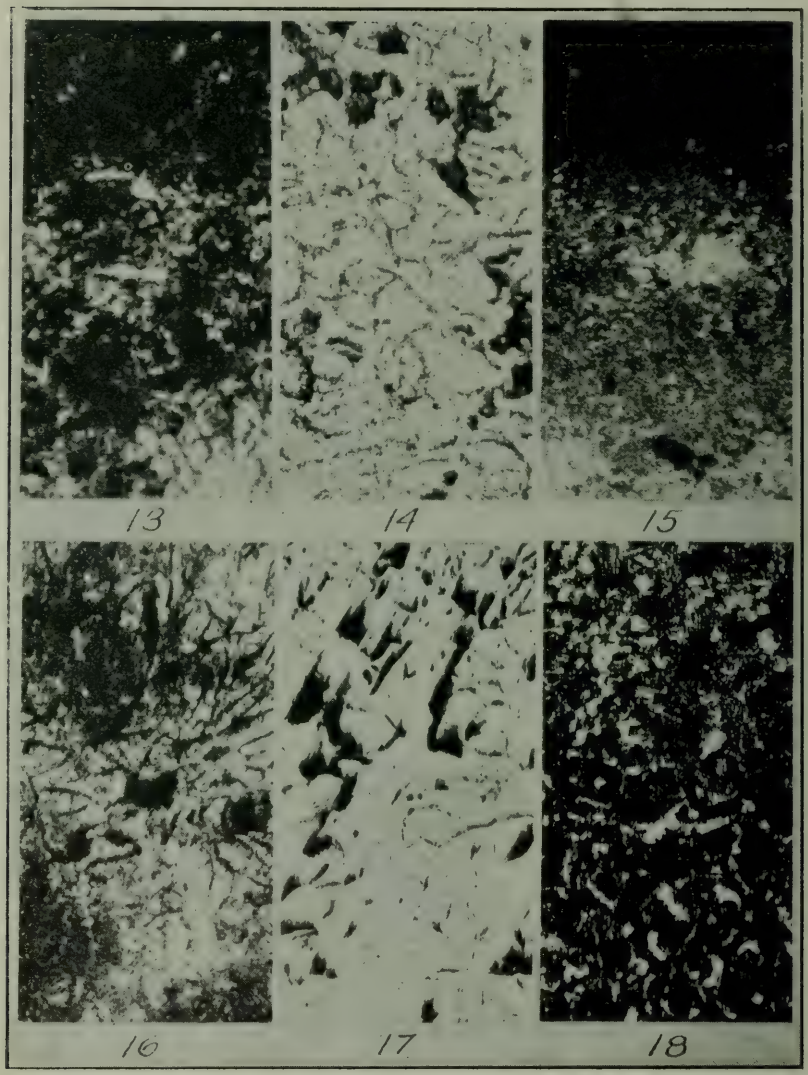

Fig. 13—Specimen 2B, carburized, cooled, edge etched. × 100. Fig. 14—Specimen 2B, carburized, cooled, center etched. × 100. Fig. 15—Specimen 2G, carburized, cooled, reheated, quenched, edge etched. × 100. Fig. 16—Specimen 2G, carburized, cooled, reheated, quenched, center etched. × 100. Fig. 17—Specimen 3E as cast, unetched. × 100. Fig. 18—Specimen 3E as cast, etched. × 100.

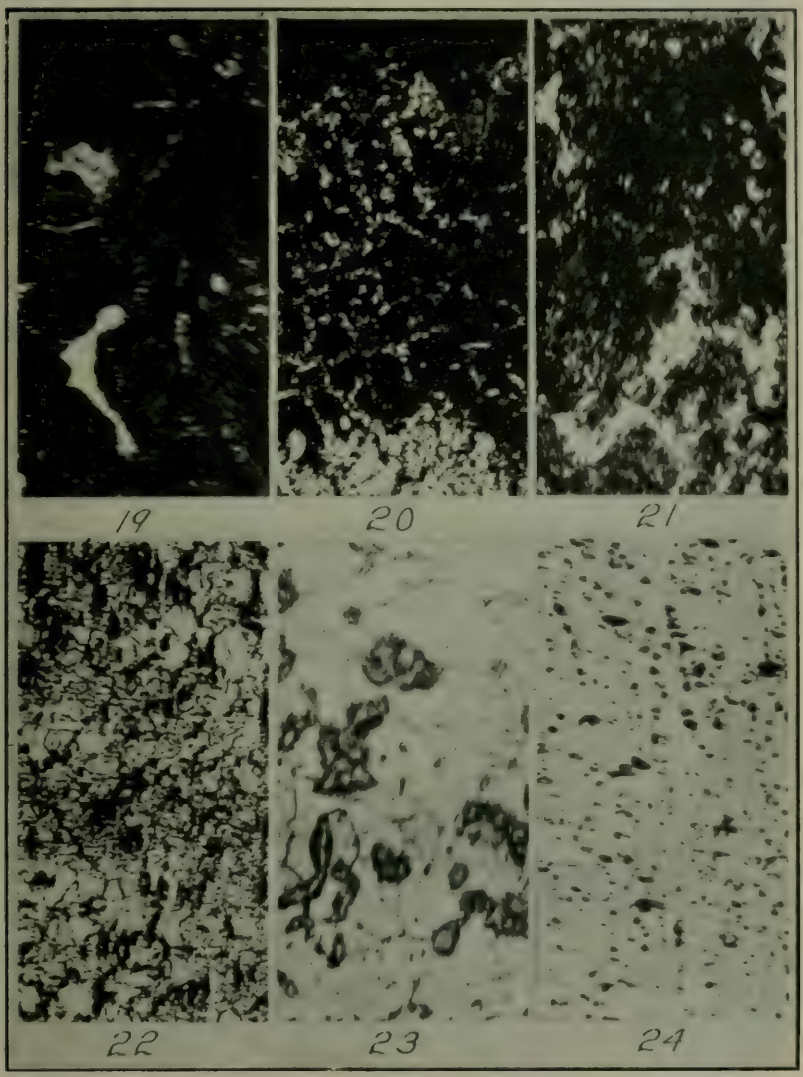

Fig. 19—Specimen 3E as cast, etched. × 400. Fig. 20—Specimen 3D, carburized, cooled, edge etched. × 100. Fig. 21—Specimen 3D, carburized, cooled, near edge etched. × 400. Fig. 22—Specimen 3D, carburized, cooled, center etched. × 100. Fig. 23—Specimen 3D, carburized, cooled, center etched. × 400. Fig. 24—Specimen 3C, carburized, cooled, reheated, quenched, unetched. × 100.

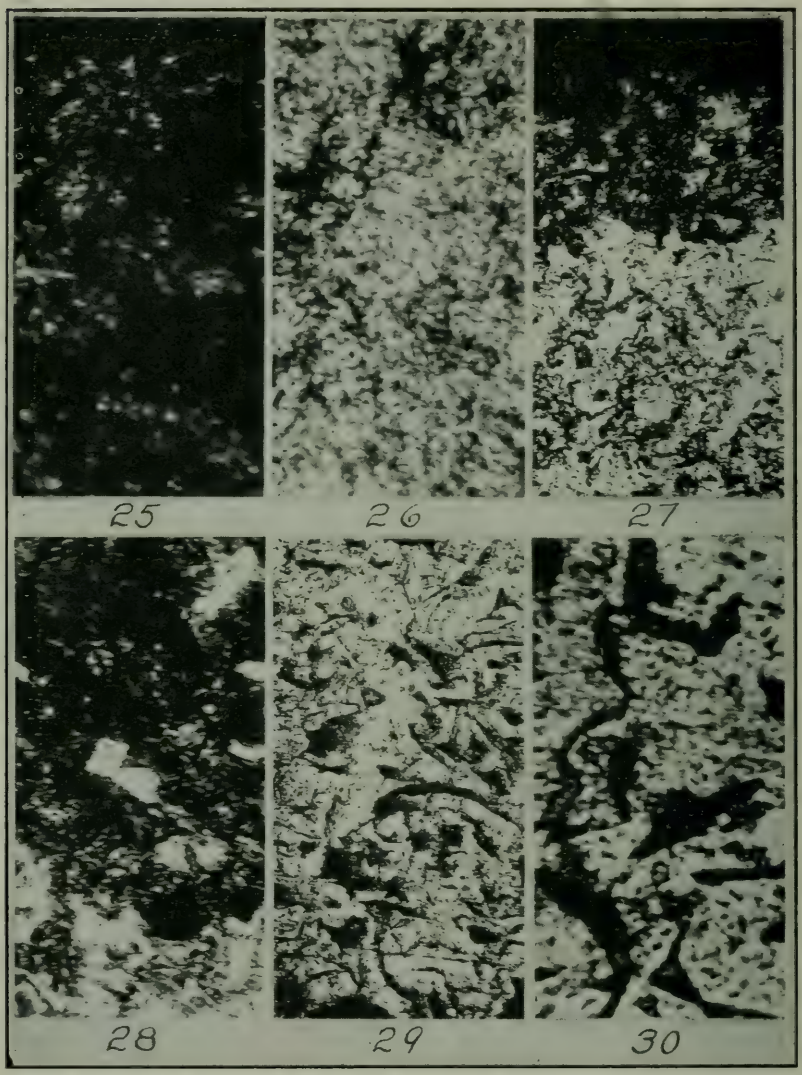

Fig. 25—Specimen 3C, carburized, cooled, reheated, quenched, edge etched. × 400. Fig. 26—Specimen 3C, carburized, cooled, reheated, quenched, center etched. × 350. Fig. 27—Specimen 3H, heated in clay, cooled, edge etched. × 100. Fig. 28—Specimen 3H, heated in clay, cooled, near edge etched. × 400. Fig. 29—Specimen 3H, heated in clay, cooled, center etched, × 100. Fig. 30—Specimen 3H, heated in clay, cooled, center etched. × 100.

broad zone at the edge which is largely pearlite. This corresponds very closely in appearance with the case of a case carburized steel except that there is free graphite present in these cases. Apparently the combined carbon in these zones is at least a little higher than in the original casting. (Note:—3B and part of 3D did not show the pearlitic zone at the edge. This may have been due to the leaky condition of the carburizing container. The quenched specimens of this series hardened properly, indicating that the outer zones must have been largely pearlite). The photomicrographs of the centers of the carburized, slowly cooled samples, show much more free ferrite than in the original casting. Evidently during the long heating the combined carbon in the center, broke down into its constituents, graphite and free ferrite. In the specimens which were reheated and quenched, some of this free ferrite has disappeared. Evidently it has been dissolvd in the formation of the semihardened structure. The photographs of sample 3H are shown in Figs. 27-30. It will be noted that here too there is a pearlitic band at the outside but that it is not as deep as those produced by heating for three hours in a carburizing material, and not nearly as deep as the one produced by 8 hours carburization. It will also be noted that there is a tendency towards decarburization at the extreme edge. The decomposition of the combined carbon in the core is noted as before.

Conclusions

This paper is not complete and exhaustive enough to be the basis for any final conclusions. There are many things yet to be worked out. Future work may alter the opinions which would be drawn from this paper alone. The paper does demonstrate the possibility of greatly improving the quality of gray cast iron. The best samples in this series were hard and at the same time had a toughness almost comparable with that of a case hardened low carbon steel. They were considerably stiffer than malleable castings. It would seem that the production of such a combination of properties from cheap gray cast iron, might have considerable commercial value.

There may be differences of opinion as to exactly what took place, during the "carburizing" heat, as well as the reasons for them. In the first place it seemed quite evident that the combined

carbon in the center decomposed into ferrite and graphite. In other words, the action was the familiar malleablizing annealing, except that the amount of combined carbon in the original casting was lower than customary. This meant that the decomposition or annealing did not require as much time. The carbon, however, which was in the plate form in the original casting was inclined to remain in that condition. This could not be considered an advantage. Fig. 24 shows that sample 3C after heat treating, contained graphite mostly in the globular form. Two other photographs of heat treated samples from bar No. 3 showed the same condition. The writer does not see the explanation.

What happens in the outer zones of these pieces when heated in contact with a carburizing material, may also be open to speculation. At the end of the run it is noted that the outer layer is mostly pearlite. Of course there was considerable pearlite in the casting to begin with. It would be interesting to try the same process on a cast iron containing as little combined carbon as possible. It seems probable that the combined carbon in the outer zone is actually increased by the "carburizing" run. Why should this take place? Does the pressure or quantity of carbon monoxide gas in the carburizing box, produce a different condition of chemical equilibrium with which a higher amount of combined carbon in the outer zone, is in balance? Why should heating favor decomposition of the combined carbon in the center and the formation of the same compound near the surface? Does it not seem reasonable that this may be due to the action of the gases generated by the carburizing material?

Another question which may well be raised, is; what composition of cast iron would be the most suitable. If the silicon is very high and the combined carbon very low, it might be possible that the excess of graphitic carbon might retain the plate form which would mean a weakness. Again if the silicon were very high would it not prevent the formation of pearlite in the outer zone? If the silicon were very low there would be a great deal of combined carbon in the casting to begin with. This might require considerable heating to break down and toughen. Also, if the silicon were low, would it favor the formation of excessive combined carbon in the outer zone and cause brittleness?

Bibliography of Hardness Testing

The following bibliography covers the literature on Hardness Testing. The work on this bibliography was carried out at the instigation of Dr. H. L. Whittemore of the U. S. Bureau of Standards and was donated to the National Research Council Committee on Hardness Testing by the American Society of Mechanical Engineers who prepared it in their Library in New York. Additional references were supplied by Dr. P. D. Merica of the International Nickel Company and Dr. H. P. Hollnagel of the General Electric Company.

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Brown, S. L. Process of hardening iron, U. S. Pat. 1190568. 1915. (In Official Gazette, Vol. 214, p. 1111). By heating it to a white heat and their immersing it in boiling NaCl for a short time.

Cain, P. H. Factors in the heat treatment of steel. 1915. (In Railway Master Mechanics, Vol. 39, p. 127-9). Contains brief note on hardening and tempering of tool steel.

Chapman, R. W. Demonstration of strain-hardening of steel. 1915. (In Nature, Vol. 94, p. 589. Abstracted Journal Iron and Steel Institute, Vol. 92, p. 306). A photograph shows the changes in the side of a steel bar due to strain.

Comparison of hardness testing apparatus. 1915. (In Machinery, Vol. 21, p. 364). The Shore scleroscope test is compared with the Brinell hardness test.

Effect of duration of drawing on physical properties of hardened nickel steel. 1915. (In Tests of Metals, p. 191-203). Data are given on Brinell hardness after drawing and quenching of hot rolled nickel steel containing 3.19 per cent of nickel. It is shown that Brinell hardness of water cooled steel is higher than when air cooled.

Effect of carbon on the physical properties of heat-treated carbon steel. 1915. (In Tests of Metals, p. 204-23). Composition of the steel is given and results of Brinell hardness tests are summarized in the accompanying tables.

Edwards, C. A. and Kikkawa, H. Effect of chromium and tungsten upon the hardening and tempering of high-speed tool steel. 1915. (In Journal Iron and Steel Institute, Vol. 92, p. 6-45. Conclusions of this paper in Engineering, Vol. 120, p. 313-4). Results of hardness tests are tabulated. It is stated that the greatest hardness is associated with the high volume.

Evans, G. S. Testing the hardness of iron castings. 1915. (In Iron Age, Vol. 96, p. 8-10. Abstracted Journal Iron and Steel Institute, Vol. 93, p. 372). Two types of testing attachments are shown: One for use with a Riehle universal machine and the other with a Tinius Olsen transverse testing machine. Method of determining hardness by the Ball impression test is described.

Examination of aluminum bronze. 1915. (In Tests of Metals, p. 244). The Brinell hardness of commercial aluminum bronze containing 89.11 per cent of copper, 10.0 per cent aluminum, and 0.94 per cent iron was found equal to 144.

Friedmann, H. Tool for hardness tests. 1915. (In Iron Trade Review, Vol. 57, p. 899). Illustrated description of a small drilling machine.

Hanley, W. Treatment of special steels. 1915. (In Practical Engineering, Vol. 52, p. 136-7). Contains brief note on hardness of nickel steels and table giving Brinell hardness for steel containing 3 and 5 per cent of nickel.

Haerten Kleiner Stahlstuecke. 1915. (In Elektrochemische Ztschr., Vol. 22, p. 66-7. Abstracted Chemical Abstracts, Vol. 9, p. 2374). Recommends a water bath covered with oil for hardening of small steel pieces.

Howe, H. M. Hardening with and without Martensitization. 1915. (In Transactions Faraday Society, Vol. 10, p. 265-70. Engineering, Vol. 99, p. 87-9. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 584). Discusses the amorphous theory of the hardening of steel by rapid cooling and the influence of the rate of cooling on the hardness of Hadfield's manganese steel.

Hydraulic hardness testing machine. 1915. (In Chemical and Metallurgical Engineering, Vol. 13, p. 646. Abstracted Chemical Abstracts, Vol. 9, p. 3208). Working on the Brinell principle of making indentations in the metal and measuring the width of the same by a special microscope.

McFarland, D. F. and Harder, O. E. Alloys of chromium, copper and nickel. 1915. (In Transactions American Institute Metals, Vol. 9, p. 119-44). Contains a note on hardness tests, with hardness numbers increasing with increase of chromium and table giving Brinell hardness numbers for a series of alloys.

McLarty. Iron, copper, etc. 1915. (In Chemical Abstracts, Vol. 9, p. 1297. Abstract of McLarty's Brit. Pat. 27141, 1913). Hardening, preserving from oxidation by subjecting them to the action of gases and vapors produced by heating a mixture of H_2O, hydrocarbons, carbohydrates, etc. Free oxygen may be withdrawn before treatment.

McWilliam, A. and Barners, E. J. Brinell hardness and tenacity factors of a series of heat-treated special steels. 1915. (In Journal Iron and Steel Institute, Vol. 91, p. 125-39). Tests were carried out with chromium-steels, nickel steels, vanadium steels. Discussion.

Mathews, J. A., and Stagg, H. J. Factors in hardening tool steel. 1915. (In Journal American Society Mechanical Engineers, Vol. 37, p. 141-7. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 582-3). Considers time of heating, speed of quenching, hardness as affected by mass, time and degree of drawing, temper, furnaces and methods of heating. Results of tests are given as curves.

Meneghini, D. Hardness tests of copper-zinc alloys. 1915. (In Iron Trade Review, Vol. 57, p. 1240). Gives the arrangement and illustration of an apparatus operating under a slight pressure exercised by a ball of small diameter. Tabulated results of hardness tests on copper zinc alloys.

Olsen, T. Machine for testing hardness. U. S. Pat. 1141881. 1915. (In Official Gazette, Vol. 215, p. 277). Including means for applying a load to a piece under test.

Portevin, A. L'essai a la bille sur les metaux et alliages bruts de coulee. 1915. (In Revue de Metallurgie, Memoirs, Vol. 12, p. 95-100. Abstracted Journal Iron and Steel Institute, Vol. 92, p. 306-7). Brinell hardness test on metals and alloys in rough-cast condition. Causes of irregular results often met with. Results of Ball tests on bronze, brass.

Portevin, A. Shape of impression by falling ball. (Comptes Rendus. Vol. 160, p. 344-6).

Schulz, E. H. Die Volumen und Formanderungen des Stahles beim Harten. 1915. (In Ztschr. Ver. d. Ingen., Vol. 59, p. 66-71, 112-6. Abstracted Iron Age, Vol. 95, p. 1399-1402). On the changes in volume and shape taking place in steel with hardening. Analysis of steels used in investigation and hardness tests.

Shepard & Porter. Hardness tests of cold-rolled steel. 1915. (In American Machinist, Vol. 42, p. 277-8. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 597, 1915). Determines the relation between the ultimate tensile strength of cold-rolled steel and the hardness number as found by the Brinell and scleroscope tests. Author believes that the Brinell hardness test gives more valuable results in determining the ultimate tensile strength than the scleroscope test.

Skillmann, V. Brinell hardness-testing of nonferrous alloys. 1915. (In Foundry, Vol. 43, p. 111-2). Describes method of testing hardness by scratching, the Brinell test. Tables show hardness of various phosphor bronze alloys of gun bronze, manganese bronze and of some common alloys as white brass, babbitt, etc.

Turpin. Essais de durete executes avec un appareil a main. 1915. (In Revue de Metallurgie, Memoirs, Vol. 12, p. 104-12. Abstracted Iron Age, Vol. 96, p. 923). A simple hand device adapted to determining hardness with a satisfactory degree of accuracy. Method of carrying out tests and of calculating the results is given.

Uber den Harteversuch an Automobil Konstruktion Stahl. 1915. (In Autom.-Rundschau, Vol. 14, p. 119-20). Hardening of steel by heat treatment.

White. Hardening copper, 1915. (In Chemical Abstracts, Vol. 9, p. 2220. Abstract of White's French Pat. 467583, 1914.) By heating it to redness or whiteness, plunging it for a short time into a hardening bath of milk of lime with additions of vegetable extracts, and then hammering it.

1916

Abbott, R. R. Heat treatment of automobile steels. 1916. (In Bulletin Society of Automotive Engineers, Vol. 11, p. 32-44). Paper and discussion containing a brief note on hardening near critical points.

Arnold, J. O. Note on the relations between the cutting efficiencies of tool steel and their Brinell or scleroscope hardness. 1916. (In Journal Iron and Steel Institute, Vol. 93, p. 102-13. Abstracted Iron Age, Vol. 97, p. 1207). States that the Brinell hardness of a properly hardened tool is a negligible factor of efficiency.

Automatic steel hardening and tempering machine. 1916. (In Machinery, Vol. 22, p. 998-9). Designed to provide for automatically and uniformly hardening and tempering steel product, especially small thin pieces.

Bray, N. H. Process of Carburizing and hardening metals. U. S. Pat. 1207848. 1916. (In Official Gazette, Vol. 233, p. 412). By heating the metal to a highly absorbent degree with an acetylene flame.

Brinell hardness perpendicular to and in the direction of forging or rolling. 1916. (In Tests of Metals, p. 123-7). Cold rolled, machined, forged steel samples were tested.

Brinell meter for hardness tests. 1916. (In Machinery, Vol. 22, p. 818). Description of the Brinell meter of the Standard Roller Bearing Co.

A convenient hardness measuring instrument. 1916. (In Iron Age, Vol. 97, p. 1195). Known as the "Brinell meter" designed to give accurate results independent of the dimensions, shape and location of the material tested.

Friedmann, H. Testing nonferrous metals for hardness 1916. (In Machinery, Vol. 22, p. 1026-8). Applications of the Brinell method in regulating methods of manufacture. Tables with hardness tests of aluminum sheets, copper sheets, etc.

Fry, L. H. What is heat treated steel? 1916. (In Railway Mechanical Engineer, Vol. 90, p. 335-7). Deals briefly with hardness produced by heat treatment.

Hadfield, R. A. Memorandum on hardness. 1916. (In Proceedings Institute Mechanical Engineers, Oct.-Dec. p. 707-11). Criticizes the methods of measuring hardness.

Hardness. 1916. (In Tests of Metals, p. 31-2). Description of hardness tests carried out with 2 brass bars of different composition as received, and after compression, annealing and cold work.

Hardening high-speed steel. 1916. (In Iron Trade Review, Vol. 59, p. 270). Directions of the Vanadium-Alloys Steel Co., distributed for hardening high-speed steel.

Hardness tests for metals. 1916. (In Times Engineering Supplement, Vol. 12, no. 504, p. 164). Description of the Brinell test, the Shore scleroscope, the limitations of all hardness tests and applications of hardness tests to plain carbon steel, carbon, tungsten, chrome, vanadium steel.

Howe, H. M. and Levy, A. G. Notes on the hardening and tempering of eutectoid carbon steel and on the Shore test. 1916. (In Proceedings of the 19th meeting of the American Society Testing Materials, Vol. 16, pt. 2, p. 5-52. Abstracted Iron Trade Review, Vol. 59, p. 372). Showing the influence of the quenching temperature and of the temperature and time of tempering on the hardness and on the microstructure of quenched (hardened) steel containing 0.92 per cent carbon. It records, further certain preliminary studies of the Shore scleroscope test. Results of numerous hardness tests are tabulated.

Improvements in the technique of Brinell hardness determinations. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 611-2. Abstracted Chemical Abstracts, Vol. 10, p. 2342-3). The Brinell method is made independent of the dimensions, shape and location of the metal mass. The "sampling error" in cutting specimens for tests is eliminated.

Latest improvements in Brinell hardness testing machines. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 58-60). A direct-reading depth gauge is carried by the Scimatco-Brinell machine and gives correct indications to 1/100 of a millimeter independent of the shape of the test piece.

McFarland, D. F., and Harder, O. E. Preliminary study of the alloys of chromium, copper and nickel. 1916. (In University Illinois Bulletin No. 93, 66 pp. Engineering Experimental Station). P. 16-8: Brinell hardness number tests were made on numerous alloys of varying composition and on some pure metals and results are tabulated.

Moore, R. W. E., and Edgecomb, H. R. Hardness testing apparatus and method. U. S. Pat. 1192670. 1916. (In Official Gazette, Vol. 228, p. 1357). Method of testing metals by means of a machine forming surface indentations.

Report of the Hardness Tests Research committee. 1916. (In Proceedings Institute of Mechanical Engineers, Oct.-Dec., p. 677-701. Engineering, Vol. 102, p. 556-8, 597-9). Detailed description of experiments made at the National Physical laboratory, on hardness with analysis of various methods for hardness determination. Results of tests on hardness of different steels and bronze. Relation between hardness and resistance to wear.

Portable hydraulic hardness testing machine. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 612). Illustrated note.

Richardson, C. E. Artificial gas-fired furnace installation. 1916. (In Journal Industrial and Engineering Chemistry, Vol. 8, p. 911-4. Abstracted Journal Iron and Steel Institute, Vol. 95, p. 378). Illustrated description of hardening furnaces.

Ricolfi, F. 1916. (In Metallurgia Italiana, Vol. 8, p. 690-9. Abstracted Journal Iron and Steel Institute, Vol. 95, p. 400). Discusses the application of the Brinell method of hardness testing for controlling the manufacture and treatment of projectiles.

Stanton, T. E. and Batson, R. G. Report of committee on hardness tests. Quite comprehensive—gives description of different methods. (Proceedings Institute Mechanical Engineers, Oct.-Dec., pp. 677-723).

Thomas, W. N. A few experiments on the hardness testing of mild steel. 1916. (In Journal Iron and Steel Institute, Vol. 93, p. 255-69). Carried out in order to show the effect of time upon the determination of Brinell's hardness number, the relation between the applied pressure and the area and the diameter of the impression, the influence upon the "hardness factor" of the work done upon the specimen during application of the load and to consider the effect of the thickness of the specimen.

Turner, T. Hardening and annealing of metals. 1916. (In Journal Chemical Metallurgical and Mining Society So. Africa, Vol. 17, p. 61-6). Deals briefly with cold working of metals and its influence on hardness.

Unwin, W. C. Memorandum on tests of hardness and resistance to wear. 1916. (In Institute Mechanical Engineers. Oct.-Dec., p. 701-5). Describes briefly Turner scratch test, the indentation methods, the Brinell hardness test, the Shore scleroscope, and the relation between hardness and resistance to abrasion or wear.

Van Deventer, J. H. Hardening and softening steels. 1916. (In Machinery World, Vol. 60, p. 15-6). Describes briefly methods of heating for hardening and tempering.

Vickers & Smith. Apparatus for determining the hardness of a body. 1916. (In Journal Society Chemical Industry, Vol. 35, p. 895. Abstracted Vickers & Smith's Eng. Pat. 11936, 1915). By causing a hard steel ball by a single blow of a hammer to make impressions simultaneously on a bar of standard hardness and on the surface to be tested.

1917

Anderson, R. J. Notes on the heat treatment of high-speed steel tools. 1917. (In Bulletin Transactions American Institute Mining Engineers, Mar., p. 408-15). Discusses the paper of Bellis and Hardy on heat treatment of high-speed steel and suggests to harden by heating under close pyrometric control.

Bellis, A. E., and Hardy, T. W. Notes on the heat-treatment of high-speed steel tools. 1917. (In Transactions American Institute Mining Engineers, Bulletin Jan., p. 61-8). Experiments on hardening of high-speed steel in which metallographic means were used to determine the correct hardening temperatures. Numerous micrographs of steel hardened at different temperatures.

Brayshaw & Yates. Hardening and tempering furnaces. 1917. (In Mechanical Engineer, London, Vol. 39, p. 108. + Abstracted Jour-

nal Iron and Steel Institute, Vol. 95, p. 378). Illustrated description of a furnace for hardening and tempering steel.

Burton, W. L. The hardening of steel. 1917. (In Mining and Engineering Review, Vol. 9, p. 292-5). Deals with the heat treatment and its influence on the composition and hardness of steel. Gives results of hardening trials of steel bars.

Chubb, T. W. Recent British hardness tests of engineering materials. 1917. (In American Machinist, Vol. 46, p. 138). It was concluded that "the Brinell hardness numbers of a miscellaneous selection of steel are not a safe guide in predicting their relative resistance to wear."

Constitution et durete des alliages cuivre-aluminum riches en cuivre. 1918. (In Metallurgie, Vol. 50, No. 45, p. 1631-3). Effect of tempering temperature on hardness of alloys containing 9-16 per cent of aluminum. Results of Brinell and scleroscope hardness tests are tabulated.

Davis, E. F. Lead hardening. 1917. (In Gas Age, Vol. 40, p. 307-10). On the use of a lead bath for steel hardening. The furnaces used in lead hardening.

Davis. Testing of sheet brass. 1917. (In Proceedings American Society for Testing Materials, Vol. 17, 2, p. 164-98). Brinell and scleroscope tests were made and results tabulated. Brinell hardness tests of annealed and hard rolled metal do not vary appreciably with the thickness of the metal. Scleroscope and Brinell tests are found to be unsatisfactory on metals below a certain limit of thickness.

Ehlers, W. A. Heat treatment of metals. 1917. (In Industrial Management, Vol. 53, p. 17-28). Describes the process of hardening, temperatures to be maintained and the use of salt solutions in hardening. Describes and illustrate a heating machine for continuous hardening and annealing with automatic heat controller and regulator.

Electrical method of hardening steel. 1917. (In Engineering, Vol. 124, p. 82-3). Description of the Wild-Barfield patented process.

Grenet, L. The penetration of the hardening effect in chromium and copper steels. 1917. (In Journal Iron & Steel Institute, Vol. 95, p. 107-17). Experiments have been made on crucible steels from Firminy. Results are tabulated.

Guillery. Hardness tests. 1917. (In Comptes Rend, Vol. 165, p. 468-71. + Abstracted Chemical Abstracts, Vol. 12, p. 266. Journal

Iron and Steel Institute, Vol. 97, p. 537. Journal American Society Mechanical Engineers, Vol. 39, p. 1035-6). Indicates a source of error in making rapid Brinell tests and method by which the error can be eliminated. Gives the mechanical arrangement used in carrying out tests and data of tests on various materials as mild steel, medium steel and nickel-chrome steel.

Hampson, D. A. How to avoid cracks in hardening. 1917. (In American Machinist, Vol. 47, p. 280). Suggests to use one brand of steel to avoid losses in hardening, to heat slowly, etc.

Hardness testing machine. 1917. (In Machinery, Vol. 24, p. 177). The "Scimatco" Brinell hardness testing machine is provided with a hydraulic press and a standard hardened steel ball.

Hatfield, W. H. Steels used in airplane work. 1917. (In Automotive Industry, Vol. 37, p. 507-9). Heat treatment and their effects on hardness of various steels, case-hardening, air-hardening.

Knight, W. On testing materials. 1917. (In Machinery, Vol. 24, p. 201-3). Notes on the interpretation of results obtained from various tests. Discusses the Brinell hardness test, the scleroscope method.

Lake, E. F. Alloy or carbon steels versus carburized. 1917. (In Mechanical World, Vol. 62, p. 3-4, 18). Briefly deals with hardness of carburized steel.

Ludwik, P. The hardness of alloys. 1917. (In Ztschr. Ver. deut. Ing., p. 547-54. Engineering, p. 444-5, Vol. 104. Abstracted Journal Society Chemical Industry, Vol. 36, p. 1180, Journal Iron and Steel Institute, Vol 97, 1918, p. 537). Varying quantities of different metals were added to copper, tin, lead, zinc, and aluminum, and the hardness of the resulting alloys was ascertained by the Brinell test.

New hardness measuring instrument. 1917. (In Iron Age, Vol. 100, p. 1119. Abstracted Chemical Abstracts, Vol. 12, p. 243). Illustrated description of an apparatus based on the Brinell principle and having a steel ball, which is pressed into the specimen by a hydraulic piston.

Nouvel appareil pour l'essai de durete des metaux a la bille de Brinell. 1917. (In Genie Civil, Vol. 71, p. 265-6). New apparatus for testing hardness by means of the Brinell method. Length of time required to carry out the test is reduced.

Parker, S. W. Mayari and nickel steels compared. 1917. (In Iron Age, Vol. 99, p. 1380-1). Description of the heat treatment; table

giving results of hardness tests of Mayari and nickel steel quenched in water from 800 degrees Cent. and drawn at various temperatures. The Mayari steel drawn at the same temperature has considerably greater hardness than the nickel steel.

Parker, S. W. Properties and structure of nickel steel. 1917. (In Iron Age, Vol. 100, p. 67-9). Shows the influence of annealing at between 125-1450 on nickel steel of 0.22 and 0.41 per cent of carbon.

The Pellin hardness-testing apparatus, a French device. 1917. (In Iron Age, Vol. 99, p. 1247). It is based upon the Brinell dynamic method and has been designed for hardness testing of different metals.

Pierce, E. H. Hardness of hard drawn copper. 1917. (In Proceedings American Society Testing Materials, Vol. 17, 2, p. 114-21). Brinell hardness tests were made both on the surface and at various points in the cross-section. It is concluded that hard-drawn copper wire is equally affected throughout its mass and that the conception of a hard, exterior "skin" is erroneous.

Pyromagnetic indicator. 1917. (In American Machinist, Vol. 47, p. 83). For indicating the critical point on steel parts being heated for hardening.

The quality of hardness. 1917. (In Engineering, Vol. 124, p. 295-6). Editorial on Professor Turner's paper on "Hardness and Hardening."

Robin, M. F. Mesure de la durete par penetration d'une molette. 1917. (In Soc. d'Encourag. pour l'Ind. Nationale, Bull. 127, p. 233-9. Abstracted Journal Iron and Steel Institute, Vol. 97, 1918, p. 536-7). Results of an investigation on hardness measurements by penetration of a circular knife-edge cutter. For measuring the hardness of steel the method is thought to give more exact results than the ball pressure test.

Thompson, J. Hardening high-speed steel. 1917. (In American Machinist, Vol. 46, p. 344). Short note on temperature to be maintained in hardening process.

Turner, T. Hardness and hardening. 1917. (In Journal Institute of Metals, Vol. 18, 2, p. 87-99. Engineering, Vol. 124, p. 254-6). Definition and measurement of hardness. Hardening of pure metals by alloying, cold work and by chilling. Hardness of copper, zinc alloys, etc.

Uranium steel. 1917. (In Tests of Metals, p. 104-5). Brinell hardness of three indifferent makes of uranium steel.

Waldo, L. Apparatus for testing the hardness of metals. U. S. Pat. 1228503. 1917. (In Official Gazette, Vol. 239, p. 44. Abstracted Chemical Abstracts, Vol. 11, p. 2188). A plummet with a conical impression point is allowed to fall upon the material to be tested to determine its hardness.

1918

Apparatus for testing the hardness of metals, 1918. (In Journal Society Chemical Industry, Vol. 37, p. 285A. Abstract of Reid and Brown's Eng. Pat. 114593, 1917). By indentation with a ball or other known weight. The amount of indentation is measured optically.

Appliances for ascertaining the hardness of metals and other solid materials. (In Journal Society Chemical Industry, Vol. 36, p. 980. Abstract of Eng. Pat. 107685, 1916). By the depth of indentation in the material caused by the predetermined pressure of a hardened ball.

Avery & Dobson. Hardness testing machine. 1918. (In Journal Society Chemical Industry, Vol. 37, p. 533A. Abstract of Avery & Dobson's Eng. Pat. 117526, 1917). By indentation of the specimen with a steel ball. The indicating mechanism consists of a pendulum or spring balance.

Ayers, J. G. A new method of obtaining Brinell hardness. 1918. (In Automotive Industry, Vol. 39, p. 457. Proceedings American Society for Testing Materials, Vol. 18, No. 2, p. 461-5). An impact substituted for a steady pressure to reduce the time required for applying the test.

Bassett, W. H. and Davis, C. H. A comparison of grain size measurements and Brinell hardness of cartridge brass. (Transactions American Institute Mechanical Engineer, Vol. 60, p. 428).

Batson, R. G. C. Value of the indentation method in the determination of hardness. 1918. (In Proceedings Institute Mechanical Engineers, Vol. Oct.-Dec., p. 463-83. Abstracted Journal Society Chemical Industry, Vol. 37, p. 703A). Deals with indentation produced by a static load and by the impact of a ball or cone.

Batson, R. G. C. Value of the indentation method in the determination of hardness. (Engineering, Oct. 25, 1918, p. 475).

Boyelle-Morins. Testing or determining the hardness of metals and other substances. 1918. (In Journal Society Chemical Industry, Vol. 37, p. 76-7A. Abstract of Boyelle-Morins Eng. Pat. 108460,

1917). By comparison of the indentations produced in the substance and in a body of standard hardness by the pressure of a hardened steel ball or the like.

Brayton, H. M. Tensile strength and hardness of steel. 1918. (In Iron Age, Vol. 102, p. 627-9. Abstracted Journal Iron and Steel Institute, Vol. 98, p. 492). Considers the relation between tensile strength and Brinell and scleroscope hardness. Their relation shown by means of graphical charts. One being known, the other can be easily ascertained without recourse to tests.

Chattaway. Machine for testing the hardness of metals. 1918. (In Journal Society Chemical Industry, Vol. 37, p. 226A. Abstract of Chattaway's Eng. Pat. 114126, 1917). By forcing a hardened ball against the article and by estimating the hardening from the diameter of indentation.

Cooke, C. J. B. Testing hardness of metals by the Boyelle-Morin apparatus. 1918. (In Proceedings Institute Mechanical Engineers, Jan.-May, p. 331-3. Abstracted Chemical Abstracts, Vol. 13, p. 1206). Illustrated description of a portable apparatus which can be used upon castings or forgings and consisting of a tube carrying a hardened steel ball. By striking a blow with a hammer, indentations are produced upon the object to be tested and upon a piece of metal of known Brinell hardness.

Craggs, J. W. Notes on testing hardness of metals. 1918. (In Journal Society Chemical Industry, Vol. 37, p. 43T-48T). (Abstracted Journal Iron and Steel Institute, Vol. 97, p. 537. Chemical Abstracts, Vol. 12, p. 1282). Reviews various methods of hardness testing and gives factors for the comparison of the results with the Brinell and scleroscope method of hardness testing.

Craggs, J. W. Effect of pressure on diameter of steel balls. (Journal American Society of Mechanical Engineers, Vol. 40, pp, 386-388).

De Forest, A. V. A simple type of Brinell testing machine for 500 kg. load. 1918. (In Proceedings American Society Testing Materials, Vol. 18, No. 2, p. 450-9). Compares 5 Brinell hardness testing machines and test results carried out on hard rolled cartridge brass.

Edwards, C. A. The hardening and tempering of steel. 1918. (In Engineering, Vol. 105, p. 267-70. Abstracted Journal Iron and Steel Institute, Vol. 97, p. 528). Discusses the principles of hardening of carbon steels and "Special steels" like nickel-steels, chromium and tungsten steels.

Edwards, C. A. A law governing the resistance to penetration of metals when tested by impact with a 10 mm. steel ball; and a new hardness scale in energy units. Prof. C. A. Edwards, D Sc. University of Manchester. (Engineering, Oct. 25, 1918, p. 469).

Edwards, C. A., and Willis, F. W. A law governing the resistance to penetration of metals when tested by impact with a 10 mm. steel ball; and a new hardness scale in energy units. 1918. (In Proceedings Institute Mechanical Engineers, Jan.-May, p. 335-69). Results of tests carried out with different materials as tin, aluminum, Muntz-metal, copper, steel, etc., are tabulated. Criticizes the various methods of estimating the hardness of metals.

Fairfax. Brinell tests of hardness. 1918. (In Mechanical World, Vol. 63, p. 127). Description of the method, calculation of the value, table of Brinell hardness caused by 10 mm., diameter ball under various loads and tables giving typical Brinell hardness for various metals and for wrought steels used in automobile construction.

Greenwood, J. N. Constitution and hardness of aluminum bronze. 1918. (In Foundry, Vol. 46, p. 322-5). Relationship between the hardness and the composition of aluminum bronze, as modified by heat treatment and by increasing percentages of aluminum. The alloys examined from 8.7-13 per cent of aluminum.

Grotts. Metallography and heat treatment of metals used in airplane construction. 1918. (In Chemical and Metallurgical Engineering, Vol. 19, p. 121-8, 191-7, 241-6). Hardness tests made on heat treated medium carbon steel, high carbon steel, chrome-nickel, chrome-vanadium steel, etc. Method and apparatus used in testing and results of hardness tests.

Guest, J. J. Hardness tests, 1918. (In Institute Mechanical Engineers, Oct.-Dec., p. 555-65. Abstracted in Mechanical Engineering, Vol. 41, No. 2, p. 173-4). Gives a formula for measurement of hardness and indicates the nature of hardness by means of a stress-strain diagram.

Hardening carbon steel. 1918. (In Journal Industrial and Engineering Chemistry, Vol, 10, p. 574). Description of an automatic electrically operated detector for use in connection with the hardening of carbon steel.

Hardening of aluminum-bronze, 1918. (In Journal Institute of Metals, Vol. 19, 1, p. 250-1. Journal Industrial and Engineering Chemistry, Vol. 9, p. 1144. Abstracted Giesserei Ztg., June 1, 1917 +). By

heat treatment. Table is given showing Brinell hardness, etc., before and after heat treatment.

Haynes, E. Stellite, alloys of cobalt, chromium, tungsten and molybednum. 1918. (In Chemical and Metallurgical Engineering, Vol. 18, p. 541-2). Tungsten and molybdenum increase the hardness to a remarkable degree.

Lake, E. F. Failure of the carburizing process. 1918. (In Proceedings Steel Treating Research Society, Vol. 1, No. 9, p. 39-45). Briefly deals with hardness of carburized steel.

Morse, F. L. Hardness testing machine. 1918. (In U. S. Official Gazette, Vol. 247, p. 271. Abstracted in Journal Society Chemical Industry, Vol. 37, p. 226A). Combining a yielding abutment, a movable plunger, an indenting projection, a cylinder connected to said abutment, a piston with a by-pass valve and a glass gage.

Richardson, G. A. Steel for gears and their treatment. 1918. (In Iron Age, Vol. 101, p. 1668-1671). Discusses the relative merits of case-hardening and oil hardening for nickel-chrome alloys, chrome-vanadium composition and other alloys containing tungsten with or without nickel, chromium, etc.

Schultz, G. Hardening and tempering certain railways materials. 1918. (In Stahl und Eisen, Dec. 5. + Abstracted in Mechanical Engineering, Vol. 41, p. 391). For all parts basic Martin steel with at most 0.12 per cent carbon is used.

Shore, A. F. Report on hardness testing: relation between ball hardness and scleroscope hardness. 1918. (In Journal Iron and Steel Institute, Vol. 98, p. 59-78, 79-88). Results of experiments are shown graphically in accompanying charts. A list of metals and materials used in the experiments. Discussion and correspondence on the paper.

Simplest hardening equipment for carbon steel. 1918. (In Electricity, Mar. 22, 1918. + Abstracted Electrical World, Vol. 71, p. 887). Description and illustration of the furnace.

Steel hardening process makes substitute for manganese steels. 1918. (In Electrical Railway Journal, Vol. 52, p. 704). By application of an oxyacetylene flame in heating iron or steel.

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STATIC AND DYNAMIC TESTS FOR STEEL

By J. M. Lessells

Abstract

The paper deals with certain static and dynamic forms of testing, the tensile test being taken as representative of the former, and the repeated shock and fatigue as representative of the latter.

Certain types of shock and fatigue testing machines are described in detail together with the experimental results obtained from such machines.

The tabulated data shows that the results obtained from the repeated shock tests have a real meaning and are closely related to those obtained from the long-time fatigue tests. Since it has frequently been asserted that there is no such relation between repeated shock and fatigue, these results are of the first importance. On this basis the repeated shock test becomes a short time fatigue test.

Another short time test is discussed in detail in which the endurance limit under fatigue is determined by measuring the deflection of a single test piece while running under a varying load. In general the paper asserts the importance of dynamic testing, cautions the use of such without proper knowledge, and establishes a relation between different forms.

Introduction

THIS paper is presented with the view of discussing some of the characteristics of static and dynamic forms of testing. The tensile test has been taken as representative of the static

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A paper presented before the Pittsburgh chapter of the Society, June 5, 1923. The author, J. M. Lessels, is engineer in charge of mechanics in the Research laboratory of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

The author is indebted to the Westinghouse Electric & Manufacturing Company for permission to publish these remarks and to P. L. Irwin for his assistance in obtaining much of the data here recorded.

forms and the repeated shock and fatigue as representative of the dynamic forms. A relation between these two latter tests is discussed in detail.

Static Testing

Tensile

The tensile test being the chief static test is first considered, this test of course, due to the speeds adopted for commercial

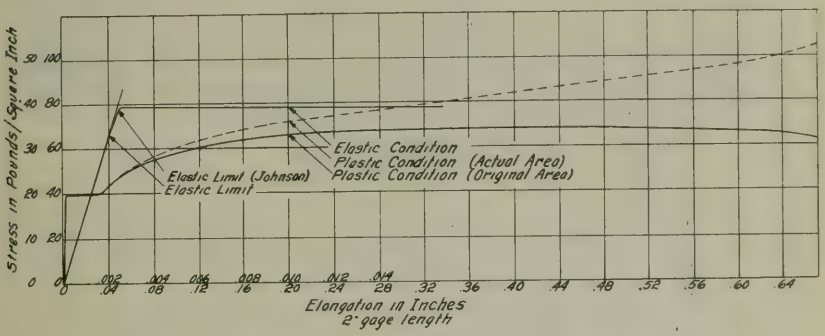

Fig. 1—Tensile Test Diagram for an 0.37 Per Cent Carbon Steel, Annealed. Elastic Limit, 33,000 lbs. per sq. in.; Yield Point, 39,600 lbs. per sq. in.; Maximum Stress (original area), 68,825 lbs. per sq. in.; Maximum Stress (actual area), 117,500 lbs. per sq. in.; Elongation in 2 Inches, 35.4 per cent; Reduction of Area, 50.6 per cent; Modulus of Elasticity, 30.8 x 10^6; Proof Resilience, 8.82 inch pounds.

testing might scarcely be classified as static, but on the basis that the test piece is stationary it is so considered in this paper.

In a tensile test, there are two values around which much discussion as to the actual meaning of the values, has taken place. Reference is made to the elastic limit and yield point. This contention is all unnecessary since there is no question that we can all agree on the interpretation of such, if we desire to do so. The elastic limit can be taken as that stress at which strain ceases to be proportional to applied load, and yield point as that stress at which an extension of 0.01 inches on a standard test bar has occurred. These values would only be suitable for low and medium carbon steels, but there is no reason at all why an interpretation of such cannot be worked out on this basis which eliminates all such expressions as "drop of the beam," etc. In this manner the yield point would be tied up completely with elastic limit, which is, as it should be.

In Figs. 1 and 2 are shown characteristic tensile test diagrams

on which these two values are recorded on the basis of the previous interpretation. With this brief discussion of the apparent difficulties of the tensile test interpretation, the more complicated forms of testing can now be considered.

Dynamic Testing

There are two forms of dynamic tests; namely the shock test and the fatigue test.

Shock Tests

The repeated shock test will alone be considered here since the other forms of tests were fully discussed by the writer in a

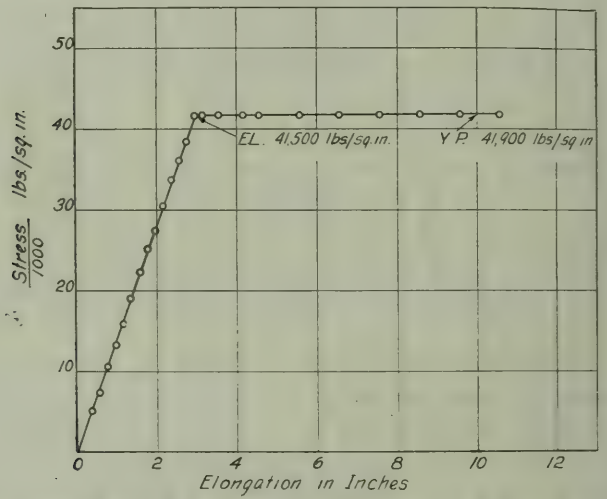

Fig. 2—Elastic Phase of the Tensile Test Diagram for a Steel Casting of 0.33 Per Cent Carbon, Normalized.

paper published in the May, 1922, issue of TRANSACTIONS. The type of machine used is shown in diagrammatic form in Fig. 3, and is called the Stanton type.

In this machine, the test piece being notched, is struck a blow over the notch alternately 180 degrees apart, the height of drop and the number of blows to fracture being recorded. Tests conducted with such a machine for a single height of drop are of little or no value and the results of such might conceivably be very misleading. Due to the possibility of being able to change the height of the drop a series of results can be obtained, commencing with a 2-inch drop and noting the number of blows to

fracture, then reducing the height of drop on each consecutive test piece until a drop of 0.3-inch has been reached. These results are then plotted so that height of the drop is the ordinate and the number of blows to fracture the abscissa. The type of curve

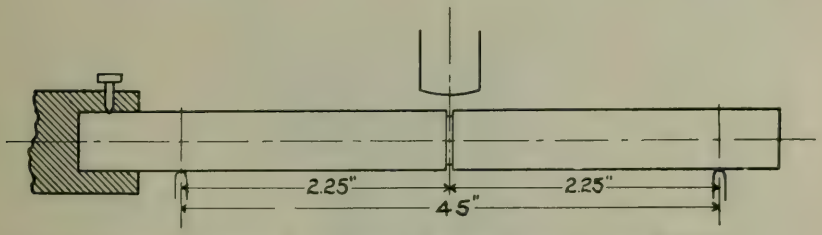

Fig. 3—Diagram of the Stanton Repeated Impact Testing Machine.

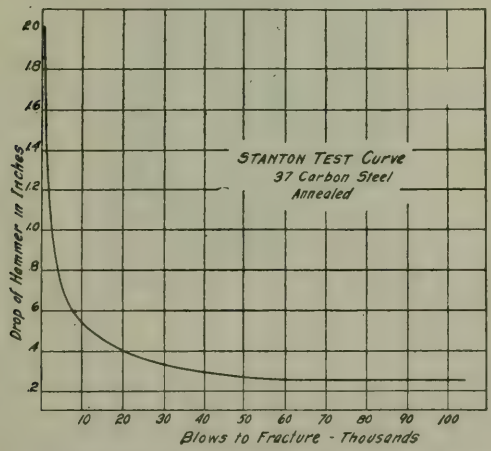

Fig. 4—Repeated Shock Test Curve for a 0.37 Per Cent Carbon Steel, Annealed.

obtained is shown in Figs. 4, 5 and 6. It will be noted that all of these curves are characteristic, just as a tensile test diagram is characteristic.

Fatigue Tests

Fatigue testing machines are of various forms, but only two will be discussed here; namely, the beam type and the cantilever type.

In the beam type, the test piece is freely supported at the

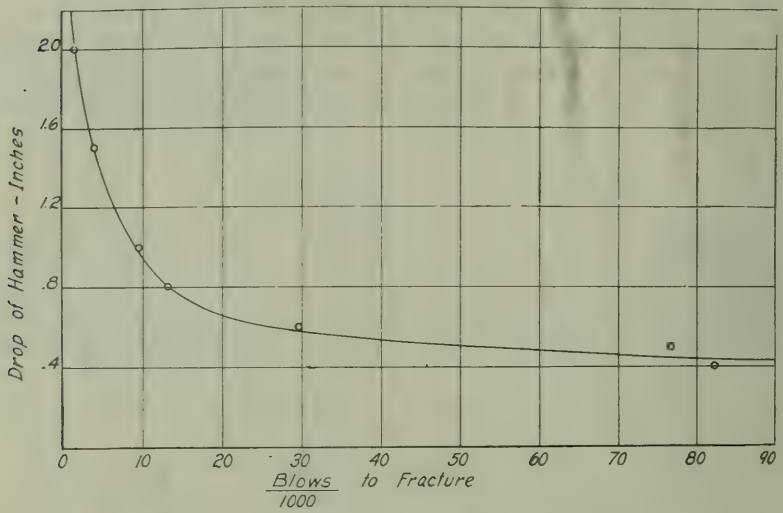

Fig. 5—Repeated Shock Test Curve for a 0.37 Per Cent Carbon Steel Heat-Treated.

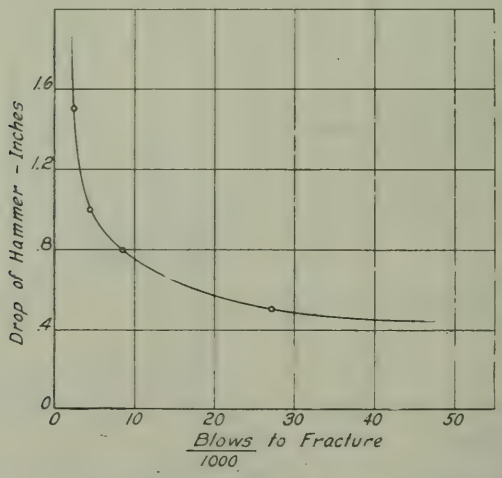

Fig. 6—Repeated Shock Test Curve for a 0.33 Carbon Steel Casting, Normalized.

ends on two ball bearings and loaded through two others, each 1½ inches from the center of the test piece. In the cantilever type the test piece is gripped at one end and is loaded at the other

through a ball bearing. Both types of machines are shown in Figs. 7 and 8. Tests are made on these machines by taking a series of test pieces and commencing with a stress approximately one-half the ultimate stress in tension, and the piece is run to destruction. The number of stress cycles to fracture the specimen, is

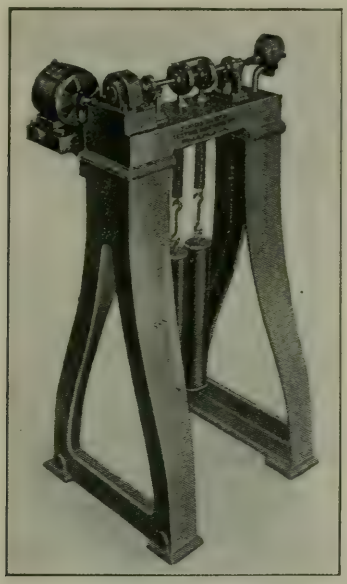

Fig. 7—Beam Type of Fatigue Testing Machine.

recorded. The stress is slightly reduced on successive test pieces until a total cycle of 20×10^6 is obtained without fracture. From the results obtained, a curve having the stress as the ordinate and the cycles of stress as the abscissa, is obtained. Such curves are shown in Figs. 9 and 10.

It will be noted that these curves are of the same general characteristic as those obtained from repeated shock tests. On the assumption that these endurance curves are asymptotic to the horizontal axis the endurance limit is taken as that stress just immediately below, that withstood for 20×10^6 cycles without failure.

Relation Between Endurance and Repeated Shock

As previously stated the curves for endurance and repeated

shock show the same characteristics in that, after certain points, small decrements of stress in the case of fatigue tests, and of height of drop in the case of repeated shock tests, give large increments in the life of the specimen, and that neither break. Since these are similar, the vertical height of the repeated shock curve to-

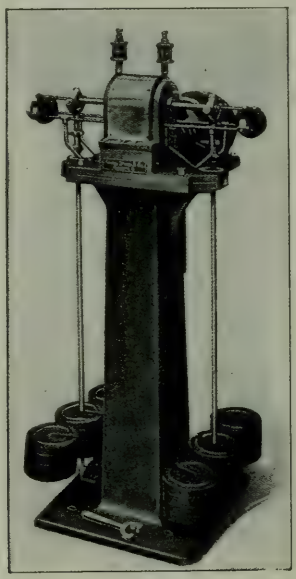

Fig. 8—Cantilever Type of Fatigue Testing Machine.

wards the right hand should be indicative of the endurance value obtained by the longer methods. To show this, a comparison of such values is given in Table 1.

In this table three steels are considered, a rolled medium carbon steel, a carbon-vanadium steel casting, and a carbon steel casting. Taking the values of the endurance limits (carbon steel as rolled) as unity, and the value from the shock resistance curve at 60,000 blows also as unity, the corresponding relative values for the annealed and normalized states are shown to be 1.01 and 1.06 for the long fatigue tests, and 1.04 and 1.08 for the shock tests. This is also repeated for the steel castings, making the cast condition the basis of comparison. It will be noted that there

is a striking similarity between the two sets of results, showing undoubtedly, that there exists a relation between fatigue and repeated shock, if the results are properly interpreted.

Short Method of Determining Endurance Limit

From what has been previously said, it will be appreciated that the determination of endurance limits is a long process, since

Table I
Relative Endurance Values from Shock and Fatigue Tests

Material	State	Fatigue Tests	Shock Tests
0.37 Carbon Steel	As rolled	1.00	1.00
0.37 Carbon Steel	As annealed	1.01	1.04
0.37 Carbon Steel	As normalized	1.06	1.08
0.3 Car.—0.18 Van. Steel	As cast	1.00	1.00
0.3 Car.—0.18 Van. Steel	As annealed	1.05	1.17
0.3 Car.—0.18 Van. Steel	As normalized	1 07	1.17
0.23 Carbon Steel	As cast	1.00	1.00
0.23 Carbon Steel	As annealed	1.10	1.16

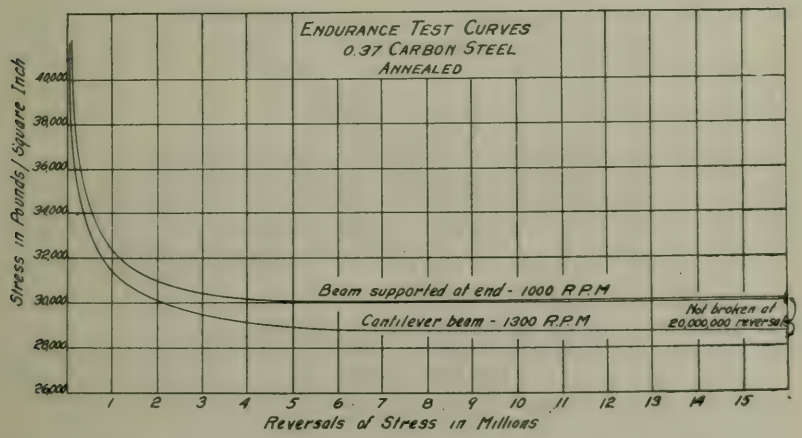

Fig. 9—Endurance Curve for a 0.37 Per Cent Carbon Steel, Annealed.

for a stress cycle of 20×10^6 the test piece must run continuously for at least twelve days. The repeated shock test can be used as

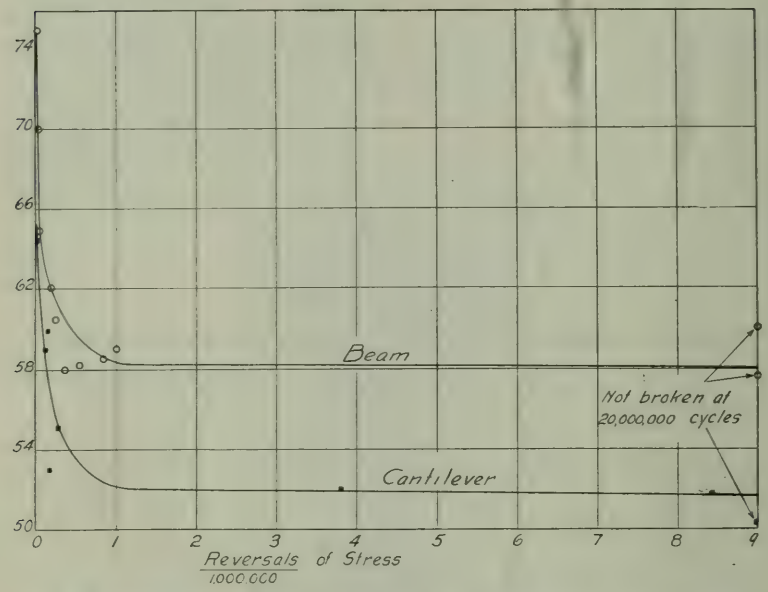

Fig. 10—Endurance Curve for a 0.37 Per Cent Carbon Steel, Heat Treated.

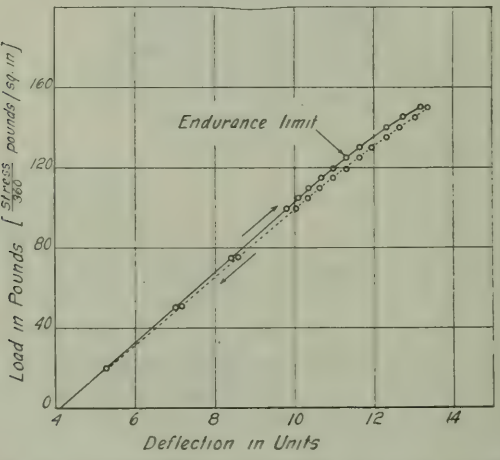

Fig. 11—Deflection Curve (Dynamic) for a 3½ Per Cent Nickel Steel.

a check on these long tests once the values from these long tests for one state of the material are at hand. There is, however, several short cuts to the determination of this endurance value.

One of these will be discussed, namely, the "deflection" method. In this test, one test alone is necessary although two are desirable and the endurance limit can be determined in thirty minutes. A mirror is fixed in the end of the rotating test piece and by a suitable arrangement of telescope and scale the values of deflection and corresponding load are obtained. From this data a curve is drawn having stress as ordinates and deflection as abscissae. The point at which stress ceases to be proportional to deflection is the endurance limit of the material. A curve of this nature for nickel steel is shown in Fig. 11. This method originally used at the National Physical Laboratory, England, gives very good results and the only limitation imposed on its use at this time by the writer, is that the endurance value so found must not exceed the elastic limit in tension.

From these remarks it will be appreciated that there is a relation between repeated shock and endurance tests. Since a series of repeated shock tests can be made in a few hours while the endurance tests take weeks, this relation will, when further worked out, tend to make dynamic testing possible commercially. Furthermore, by the development of such short methods as that of deflection, the time of determining endurance limits for steel under reversed stress will be further reduced. The only caution which the writer advances is that we should know these tools thoroughly before we begin to apply them. Otherwise, repeating the old adage, "a little knowledge may become dangerous."

Conclusion

In conclusion the writer wishes to emphasize the importance of dynamic testing and believes that in the future the use of such will be largely extended towards obtaining the best material for specific applications.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 96. Can the structure of a piece of steel be determined by the microscope applied to the fracture of a cross section, without polishing and etching the fracture, say of a stamping die 6 x 2 x 3½ inches, that has been hardened and broken in half, that is, are the different structural phenomena known as austenite, martensite, sorbite, ferrite, etc., so determinable?

QUESTION NO. 97. What degree of heat is required to change austenite to martensite, troosite, etc?

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 67. What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel.

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

QUESTION NO. 93. What are the more common methods of quenching ordinary taps? Are they quenched all over and the shanks drawn, or are they quenched only on the threaded portions; or are both the threaded portions and the tangs quenched, leaving the center portion of the shank soft?

QUESTION NO. 94. What are the most salient causes of the explosive disruption of many hardened steel articles?

QUESTION NO. 95. What is meant by "self hardening" steels?

Reviews of Recent Patents

1,450,947. Forging Press. David R. Gill, Erie, Pa., assignor of one-half to Harold M. Sturgeon, Erie, Pa.

This invention relates to a forging press which comprises a plurality of forging dies each having forging surfaces encircling the axis of the pass, one end of said forging surface being out of the plane of the other end thereof and the radius thereof progressively decreasing from the entrance end of the exit and thereof, said dies being interjacent of each other and forming a conically shaped pass therethrough, and mechanism adapted to support said dies and rotate each die around an axis offset from the axis of the other die.

1,451,333. Art of Making Electrolytic Iron. Frederic A. Eustis, Milton, Carle R. Hayward, Quincy, and Henry M. Schleicher and Donald Belcher, Boston, Mass., assignors, by direct and mesne assignments, of one-half to said Eustis, and one-half to Charles Page Perin, New York City.

This refers to an art of making electrolytic iron which comprises reducing a ferric solution by means of an electric current to a ferrous state, and then transferring the ferrous solution to a separate electrolytic cell to which the ferric solution has no access and depositing iron from the ferrous solution by electrolysis in said separate cell.

1,452,232. Alloy. Carl J. Zaiser, Milwaukee, Wis., assignor to American Metal Products Company, Milwaukee, Wis., a corporation of Wisconsin.

This patent refers to an alloy consisting of the following ingredients in substantially the following proportions, namely: Iron—13 to 60 per cent; Copper—82 to 30 per cent; Aluminum—5 to 10 per cent.

1,452,480. Apparatus for Casting Metals. Nathaniel K. B. Patch, Buffalo, N. Y., assignor to Lumen Bearing Company, Buffalo, N. Y., a corporation of New York.

This invention relates to an apparatus for casting metals under the pressure of centrifugal force, comprising a rotatable head, and a molding flask mounted on said head to rotate therewith, said flask having a molding cavity in its upper portion and a comparatively deep well for molten metal in its lower portion communicating with said molding cavity.

TRANSACTIONS
of the
American Society for Steel Treating

Vol. IV Cleveland, November, 1923 No. 5

THE STEEL TREATERS' MOVEMENT

An editorial from *Iron Age*, Oct. 18, 1923.

THE demand for an organization such as the American Society for Steel Treating was strongly demonstrated during the week of Oct. 8 to 12 in Pittsburgh. At its fifth annual gathering this society successfully put through a technical program and a steel exhibition which would reflect credit on a much older body. In the quality of the papers presented, in the scope of the products exhibited, and in the attendance, the meeting was a surprise to some of the most ardent steel treaters.

A feature of the convention from a technical standpoint was the high standard set by the program as a whole. In a single session the names of some of the most prominent metallurgists of the country on the list of participants made it an occasion that recalled meetings only a few years ago of the steel section of the mining engineers. A second feature was the general youthfulness of the membership, testifying to enthusiasm in their work and to the impelling power behind the accomplishment of the future. Here, in a comparatively new field, or one in which scientific knowledge, methods and apparatus are transforming a crude art, are possibilities from which much will be heard in the near future.

The exhibition, commercially and in every other way, was a success and now ranks close to the older one which is a feature of the annual gathering of American foundrymen. There were some suggestions that there is danger of giving too much prominence to the commercial side. It is hoped that the commercial features will not be overstressed or to the

point of detracting from the technical possibilities of so promising an organization. Besides the usual showing of heat treating equipment of all kinds were the attractive exhibits of large and small steel companies and machine tool interests.

The new society is thus affording a meeting place, not only for the steel treater and metallurgist, but for all steel makers and users who would have American steel products benefit to the fullest extent from the scientific advance that is now so prominently before the industry.

STEEL TREATING FIELD EXPANDS

An editorial from *Iron Trade Review*, Oct. 18, 1923.

AMERICA'S youngest of the larger technical organizations, the American Society for Steel Treating, continues to attract attention by its vigorous growth. At Pittsburgh from Oct. 8 to 12, the society held the largest convention and exposition it has yet attempted and the unqualified success was a tribute to the sound and mature judgment of the management. Within three years, or since formation of the society in 1920, its membership has grown 50 per cent, or to approximately 3000 members. The membership is open to "the man at the fire" as well as to the metallurgist and the plant executive and the society is proud of the fact that it has been able not only to retain its membership but has been able to show gains in all classifications.

As is widely recognized the art of heat treatment has made its most rapid advance since the war, thus it is only natural that the American Society for Steel Treating in its growth and activities should reflect the increasing interest in that field. Registration figures at Pittsburgh showed the degree to which the organization is doing that. Total registration reached nearly 1800 of which 1492 were listed as members. With a net membership of 3000, the attendance of this year's convention was nearly 50 per cent and about 10 per cent better than at Detroit last year. Technical sessions at which

heat treatment problems were discussed were unusually well attended. The exposition covered one-third more space than in 1922 and yet was not sufficient to provide for all applications. During the five days the doors were open it is estimated over 40,000 people passed through, thereby establishing a new record.

Already the society is feeling need for expanding its field and is developing a new constitution defining its scope. As organized at present the purpose of the society is "to promote the arts and sciences connected with the treatment of iron and steel" and refers more specifically to the treatment subsequent to the manufacture of the material. In the utilization of alloy steels, the manufacture is becoming an important consideration. In addition, certain nonferrous metals are demanding attention as regards heat treatment. Therefore, appreciating the importance of the rapidly widening field the purpose of the society in the proposed constitution has been made to read "to promote the arts and sciences connected with either the manufacture or treatment of metals, or both."

The proposed broadening of the field of the society is logical, even though the "manufacture of metals" is almost limitless in its scope under unrestricted interpretation. If the proposal is adopted and the society directs its attention to the treatment of metals and to such phases of their manufacture as are pertinent to their subsequent treatment or use, it will be found the field is sufficiently large to absorb all the energies of members of the organization for years to come.

SOME TRADE PRESS COMMENTS ON CONVENTION

IT IS indeed gratifying to us to read some of the interesting comments made by several of the trade publications in their reviews of the Fifth Annual Convention and Exposition of the American Society for Steel Treating.

In a twelve-page review of the activities of the convention and exposition the *Iron Age* of October 18, says in part, that—

"An organization which can successfully stage a technical convention and exhibition of the high order and magnitude of the

one held in Pittsburgh, October 8 to 12, by the American Society for Steel Treating, at once takes its place in the front rank of societies of this class. That this has been possible after only four years of existence is the striking fact. The event, both from the technical and exhibition standpoint, has become one to be looked forward to with keen interest. Out of a total membership of over 2700 there was a registered attendance of nearly 1500, exceeding any previous meeting. The membership registered at Detroit a year ago was about 1250. In expansion, enviable progress was made in that the net increase in membership in good standing last year was about 18.75 per cent.

"The technical sessions without exception were featured by large audiences and an enthusiasm naturally the accompaniment of a large group of comparatively young men. The papers on the whole compare favorably with those in the programs of some of the much older technical organizations.

"The steel exhibition was the most successful of the kind ever held anywhere and it was also the largest. Entire satisfaction was voiced by nearly all those who had booths, many of them reporting excellent business booked or in prospect. The experiment of not opening the exhibition until afternoon of each day appeared to be a success."

Iron Trade Review

The *Iron Trade Review* of October 18 in a nine-page review of the exposition and convention, makes the following comments:—

"Without reservation the Fifth Annual Convention and Exposition of the American Society for Steel Treating held in Pittsburgh, October 8-12, may be judged the most outstanding yet conducted by that society. Registration reached a total of approximately 1800 of which 1492 were classified as members. Thus on the basis of a total society membership of 3000, the attendance represented almost 50 per cent, a figure probably never before reached by the larger technical organizations.

"Technical sessions in the morning were held at the

William Penn hotel, while the afternoon meetings were conducted at Motor Square Garden, where the exposition was in progress. Attendance at these meetings was unusually large and may be attributed to the facts that no simultaneous meetings were held and the opening of the exposition was arranged so as to offer little interference to the operation of the program. Motor Square Garden is located six miles from downtown Pittsburgh, but in spite of this, the attendance there broke all previous show records, it being estimated that upwards of 40,000 people passed through during the five days. Two floors were devoted to the exhibits which represented a considerably wider range of equipment than last year. The total floor space was about one-third larger than in 1922, nevertheless it was necessary to refuse many applications."

Chemical and Metallurgical Engineering

Chemical and Metallurgical Engineering in its October 22 issue devoted four pages to a review of the exposition and convention. A part of this review is as follows:—

"The Fifth Annual Convention and Exposition of the American Society for Steel Treating at Pittsburgh the week of October 8 was a great success from every viewpoint. It was well attended, the papers presented at the technical sessions were excellent and the discussions following these papers were lively. The exposition was one-third larger than last year and was visited by 60,000 persons.

"The steel exposition was held at Motor Square Garden, which, though 6 miles from the William Penn hotel, the convention headquarters, proved to be an excellent building for such an exhibit. Gas, air and electricity were available, and consequently a large portion of the exhibit consisted of actual industrial operations. Real progress in heating methods, testing methods, control devices, heat-resisting metals and other refractories was evident."

FIFTH ANNUAL CONVENTION AND EXPOSITION

BEYOND all fear of contradiction, the Fifth Annual Convention and Exposition of the American Society for Steel Treating held in Pittsburgh, Oct. 8 to 12, was an unqualified success. From the standpoint of the quality and number of exhibits at the exposition, the high quality of technical and practical papers presented at the technical sessions, and the unprecedented attendance of members and guests, mark this convention as unequalled by all previous ones.

The members of the Pittsburgh chapter are to be congratulated upon the very successful way in which they did their part toward the success of the convention and exposition. It was largely due to the untiring efforts of all of the Pittsburgh chapter members that the convention and exposition was such a decided success, proving to be of great interest not only to the technical man but to the practical man as well.

The number and variety of exhibits at this convention was fully one-third larger than the number exhibiting at the Detroit convention last year, and the amount of floor space used in presenting the exhibits was fully 50 per cent larger than that used last year. The exhibits were assembled on the main floor and subfloor of Motor Square Garden, the booths in the subfloor having an Egyptian setting. One of the main features of the subfloor was that of an exact replica of the tomb and mummy of the ancient Egyptian ruler, King Tutankhamen. The main floor was very artistically decorated and presented a most attractive and pleasing picture. Many live exhibits were in operation. Music was furnished both afternoon and evening by a large band on the main floor and by an orchestra on the subfloor.

For those who were unable to be in attendance at the Pittsburgh convention, an outline of the activities undoubtedly will be of interest. The principal technical papers were presented at the morning sessions in the ball room of the William Penn hotel. The exhibition hall was open in the afternoon and evening only, so that the members and exhibitors might have the opportunity of attending the technical meetings. The opening meeting and first technical session was held at 10 a. m. on Monday, Oct. 8, at which time W. J. Merten, chairman of the Pittsburgh chapter presided. After

an address of welcome by Mr. Merten, J. Trautman Jr., general chairman of the Pittsburgh chapter convention committees gave an address of welcome on behalf of the committee; following Mr. Trautman was H. M. Irons, representative of Mayor William Magee, who welcomed the society to Pittsburgh. A. L. Humphrey, President of the Pittsburgh Chamber of Commerce then gave an address of welcome on behalf of the industries of Pittsburgh. President Tillman Danis Lynch of the American Society for Steel Treating then gave a speech in response to the previous speakers, thanking them for their very cordial welcome to the Steel City. After the preliminary speeches, the meeting then entered into its technical session, the program consisting of the following papers:

The Manufacture of Automobile Leaf Springs—C. G. Shontz, metallurgist, Perfection Spring Co., Cleveland. (Presented by title.)

Metallography and Testing of Oxyacetylene Welds—J. R. Dawson, research metallurgist, Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y.†

Some Observations on Furnaces and Fuels, Including the Electric Furnace for Heat Treating—E. F. Collins, consulting engineer, General Electric Co., Schenectady, N. Y.

The Tempering of Tool Steels—J. P. Gill and L. D. Bowman, metallurgists, Vanadium-Alloys Steel Co., Latrobe, Pa.

Abnormal Grain Growth in Cold-Rolled Low-Carbon Steel—V. E. Hillman and F. L. Coonan, metallurgist and assistant metallurgist, Crompton & Knowles Loom Works, Worcester, Mass. (Presented by title.)*

The official opening of the exhibition was at 1 p. m. All registration of members and guests took place at Motor Square Garden. At 3:30 p. m. the afternoon technical session was held in the meeting room at Motor Square Garden. The program for this technical session is as follows:

The Annealing of Sheet Steel—Francis G. White, metallurgical engineer, National Enameling & Stamping Co., Granite City, Ill.**

Automobile Sheet Steel Specifications—H. M. Williams, metallurgist, General Motors Research Corp., Dayton, O.

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†Published in October, 1923, TRANSACTIONS, page 467.
*Published in August, 1923, TRANSACTIONS, page 162.
**Published in August, 1923, TRANSACTIONS, page 121.

Tuesday, Oct. 9

Tuesday morning at 9:30, the morning technical session was opened by the chairman, A. H. d'Arcambal. The program for this session was as follows:

Measurement of Carbon Penetration in Carburized Steels—S. P. Rockwell, consulting metallurgist, Hartford, Conn., and Frederick Downs, chemist, New Britain Machine Co., New Britain, Conn.

Case Hardening and Other Heat Treatments as Applied to Gray Cast Iron—H. B. Knowlton, instructor, Central Continuation school, Milwaukee.*

The Influence of Barium Carbonate upon Wood Charcoal Used for Cementation—B. F. Shepherd, Metallurgical department, Ingersoll-Rand Co., Phillipsburg, N. J.

Salt Baths and Containers—Sam Tour, metallurgist, Doehler Die Castings Co., Brooklyn, N. Y.

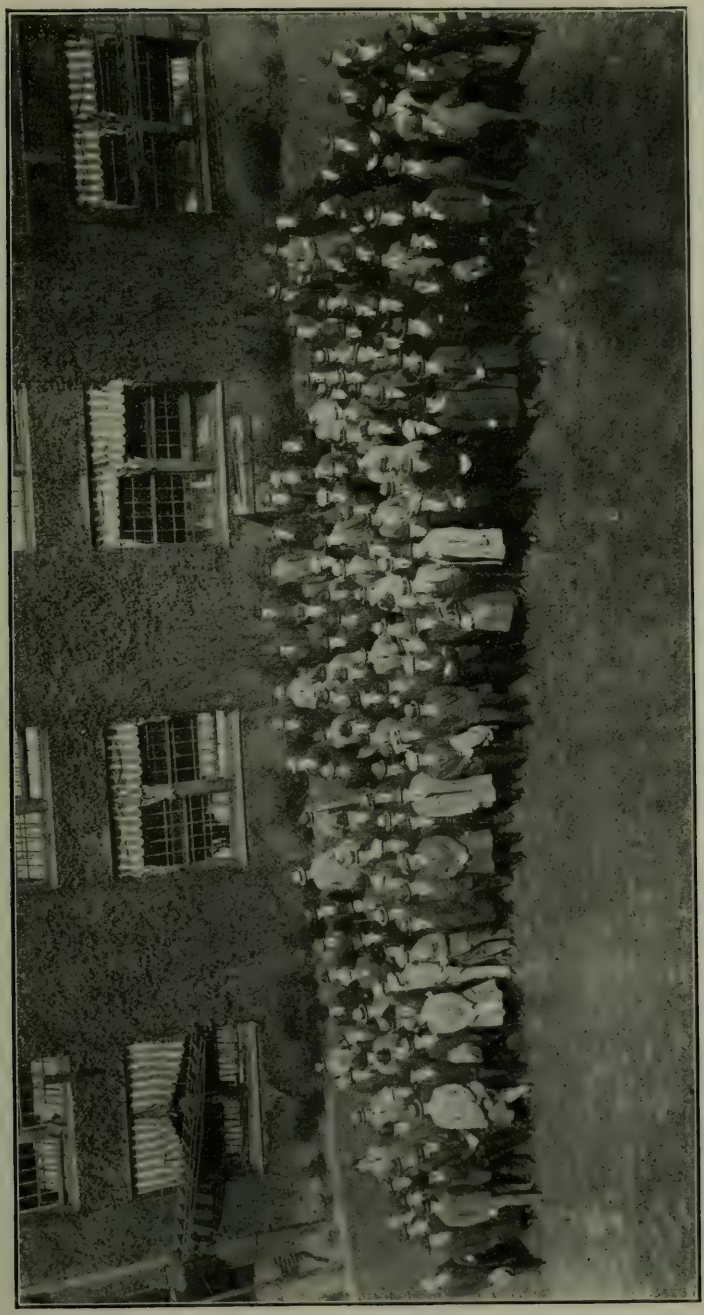
The Thermal Treatment of the Light Alloys of Aluminum and Copper—A. M. Portevin and Francois LeChatelier, Paris, France. (Presented by title.)

At 3:30 p. m. a Round Table discussion under the direction of the Standards committee was called to order by Chairman R. M. Bird in the meeting room at Motor Square Garden. At 9:30 p. m. the annual smoker and entertainment, sponsored by the members of the Pittsburgh chapter was held in the ball room of the William Penn hotel. This entertainment was attended by large numbers of members and guests and the vaudeville stunts which were presented were indeed interesting and entertaining. The members of the American Society for Steel Treating look forward each year to the smoker and we are sure that this year's program did credit to the members in charge of arrangements.

Wednesday, Oct. 10.

The annual meeting of the society was held at 9:30 a. m. on Wednesday, Oct. 10, in the ball room of the William Penn hotel, president T. D. Lynch presiding. As the first order of business, President Lynch requested that each of the chapter delegates arise and announce their names for the stenographer's report. Twenty-four chapters were represented by official delegates.

*Published in October, 1923, Transactions, page 494.



The Group of Members and Guests who visited the Westinghouse Electric & Manufacturing Company's plant in East Pittsburgh, Tuesday afternoon, Oct. 9, 1923.

The next order of business on the program was the report from the tellers of election which was read by C. G. Shontz, chairman of the committee. The result of the balloting was published on page 449 in the October issue of TRANSACTIONS. The newly elected officers are as follows: for president, one year, Dr. George K. Burgess, director of the Bureau of Standards, Washington; for second vice president, two years, Robert M. Bird, engineer of tests, Bethlehem Steel Co., Bethlehem, Pa.; for treasurer, two years, Dr. Zay Jeffries, research bureau, Aluminum Co. of America, Cleveland; for director, two years, J. Fletcher Harper, research engineer, Allis-Chalmers Mfg. Co., Milwaukee. After the tellers' report, president Lynch called for the newly elected officers to arise so that they could be officially introduced to the membership.

President Lynch then presented his annual report of the activities of the American Society for Steel Treating for the year 1922-23, which is published in full, commencing on page 571 of this issue of TRANSACTIONS.

Upon the conclusion of the report, the meeting then extended a hearty vote of thanks to President Lynch for his report and very capable leadership during the past year.

The next order of business was the report of J. V. Emmons, national treasurer of the society, who read and interpolated his financial report for the last fiscal year. Mr. Emmons' report is as follows:

"In reporting the financial status of the society, attention is first called to the Certified Financial statement for the year 1922 as published in the TRANSACTIONS of May, 1923. This statement was the most complete ever published by our society and in fact was more complete in detail than any statement that has come to my knowledge from other societies.

"Since the last annual meeting, the sum of $3,000 was set aside by the board of directors for the principal of the Henry Marion Howe Medal fund. The sum of $10,000 was set aside from the proceeds of the 1922 convention as a permanent convention reserve, in order to fortify the society against disaster from a financially unsuccessful convention. The principal of these two funds was invested in United States government bonds.

"During the year 1922, the society not only lived with its in-

come, but made substantial additions to its reserves and surplus.

"At the beginning of the year 1923, the finance committee established a budget of expected receipts and expenditures for the year based upon our experience for 1922. This budget was subdivided by the treasurer into monthly items.

"The following is, therefore, a report of progress for the first eight months of 1923:

"The budget expected receipts, exclusive of convention, for the eight months ending Sept. 1, to be $33,084 with expenditures of $32,559. The actual receipts were $37,270.01 with actual expenditures of $34,963.50. The receipts were, therefore, $4186.01 or 12 per cent above our budget expectations. Our expenditures were $2404.50, or 7.4 per cent above our budget expectations. Our receipts, therefore, increased faster than our expenditures. The surplus on Aug. 31 was $11,406.38 of which $673.25 was miscellaneous accounts receivable, $3011.25 advertising accounts receivable, $2514.24 office furniture and fixtures, $962 inventory of paper and bindery stock, $4245.64 working cash."

The membership unanimously accepted the treasurer's report and extended a hearty vote of thanks to him for the very capable service he rendered during his two years in office as treasurer of the American Society for Steel Treating.

W. H. Eisenman, national secretary of the society then presented his annual report which is published in this issue of TRANSACTIONS, commencing on page 578.

The report of the national secretary was unanimously accepted by the membership and a hearty vote of thanks was extended to him.

The next order of business on the program was the report by Robert M. Bird, chairman of the national Standards committee of the American Society for Steel Treating who reported the treatise on pyrometry by Sub-committee IV, and the tentative recommended heat treating practices for carbon and high-speed tool steels of which Sub-committee I, which appeared in the September, 1923, issue of TRANSACTIONS; likewise he reported the progress made by the other two sub-committees, namely Sub-committee II, that on the general heat treatment of steels and Sub-committee III on case hardening of steels.

Mr. Bird went into considerable detail pointing out some of the difficulties that the various committees had encountered in carrying out their work. He reported that during the round table discussion session held by the Standards committee, on the previous day, many of the problems encountered by the various committees were discussed in detail. He indicated that it was the sense of the round table meeting that the name of the present "Standards

A Booth on the Main Floor of Motor Square Garden
(Courtesy of *Iron Trade Review*)

committee" be changed to "Recommended Practices committee" and that this opinion would be given to the Board of Directors, for consideration.

He also pointed out that the three national societies namely, The American Society for Testing Materials, The Society of Automotive Engineers and The American Society for Steel Treating have definitions of heat treatment terms which are basically in accord with each other but differ in minor details, and in consequence a Tri-Society committee was made up of a representative from the controlling committee of each of these three societies. This Tri-Society committee has met at frequent intervals (and through correspondence) in an effort to establish a uniform set of heat treatment definitions. Mr. Bird said that our representative, John E. Halbing, had reported to the Standards committee that

the Tri-Society committee has been unable to arrive at a conclusion.

Mr. Bird pointed out that there is a vital need for a common set of heat treatment definitions and that it was his opinion that there is no other society or agency under which the work of attaining such a set of definitions falls so properly as it does to the American Society for Steel Treating and it was his hope that the society, would actively undertake this proposition during the next year.

Following Mr. Bird's report a motion was made by A. W. F. Green that it is the consensus of opinion of the meeting that the name of the present "Standards committee" be changed to "Recommended Practices committee" and that this suggestion be transmitted to the Constitution and By-Laws committee. A short discussion was then held concerning the differences in the definitions of various heat treating terms. A vote of thanks was extended to the members of the Standards committee and its Sub-committees for their very capable work during the past year.

The next order of business was the report by S. M. Havens, chairman of the Constitution and By-Laws committee of the American Society for Steel Treating, who outlined in considerable detail the work that this committee has been doing the past year, pointing out that it is advisable for this society to revamp its present constitution so that it would more nearly comply with the laws of the principal states and especially the state of Ohio, under which the Society is incorporated, and as a result the committee had drafted a proposed Constitution and By-Laws which would, if accepted by the membership, replace the one which we are now using. This proposed draft of the new Constitution and By-Laws had been distributed by mail to all members of the society during the month of August. Copies of the "Proposed Constitution and By-Laws" were then distributed among the members for ready reference in respect to the various changes therein and Mr. Havens then took up, point by point, the principal variations from the present constitution, for the purpose of discussing them. He pointed out that these proposed changes in the constitution are not in their final form but were submitted as suggestions for the discussion and approval or rejection by the membership. He indicated that while the Board of Directors had approved the draft

as it now stands, the matter of adopting it rests entirely with the membership and that it should be very carefully considered and discussed prior to its adoption.

Considerable discussion was held in reference to the changing of the Society's name due to the fact that the object of the Society which originally pertained to "the promotion of the arts and sciences connected with the treatment of iron and steel" had been proposed to read "the promotion of the arts and sciences connected with either the manufacture or treatment of metals, or both." With this change in the object of the Society activities to include metals other than iron and steel it was suggested that the Society's name likewise be broadened. Such names as the American Society for Metal Treating, the American Metallurgical Institute, the American Society for Steel Treating and Metallurgy, etc., were suggested. The majority of those present at the meeting considered it inadvisable to make any change in the name of the Society at the present time.

Considerable discussion was held pertaining to Article 10 of the proposed constitution relating to the number of officers and the Board of Directors of the Society. The delegates from the Detroit chapter proposed certain changes with reference to the method of the selection of the national Nominating committee. After considerable discussion the Detroit delegates withdrew their proposals.

Some discussion pertaining to the selection of the Nominating committee ensued and a motion was then made and carried that it was the consensus of opinion of the assembled members, that representation on the national Nominating committee of the American Society for Steel Treating should be by chapters, that is, each chapter of the Society should be represented on this committee. It was further moved and approved by the meeting that only one representative from each chapter should have membership on the Nominating committee. These motions were in the form of recommendations to the national Constitution and By-Laws committee, with authority to work out the details necessary for proper application of the principle involved.

The Wednesday afternoon technical session was held in the meeting room of Motor Square Garden at 3:30 under the chairmanship of J. J. Crowe. The program for this session was as follows:

The Manufacture of Heavy Forgings—W. R. Klinkicht, foreman, heat treating department, Pollak Steel Co., Cincinnati.

Determining Heat Treating Costs—H. F. Wood, metallurgist, Wyman-Gordon Co., Ingalls-Shepard division, Harvey, Ill. (Presented by title.)

Practical Heat Treatment of Carbon, Alloy and High-Speed Steel Tools—J. J. Jones, metallurgist, Pittsburgh.

Spark Testing of Steel—Don Stacks, consulting metallurgical engineer, Hartford, Conn. (Presented by title.)

Some Fundamental Defects of Hardened Steel—Dr. Leslie Aitchison, Birmingham, England. (Presented by title.)

At 9:30 p. m. the annual informal dance of the Society was held in the Ball room of the William Penn Hotel. This party was very well attended and all spent a very delightful evening.

Thursday, Oct. 11

The morning technical session was held in the Blue room of the William Penn Hotel and was called to order at 9:30 by Professor H. M. Boylston. The following papers were presented at this session:

*Effect of Heat Treatment on Lathe Tool Performance and Some Other Properties of High-Speed Steels,** by H. J. French, Jerome Straus and T. G. Digges was presented by H. J. French, physicist of the Bureau of Standards.

Secondary Hardness in Austenitized High Chromium Steels, was presented by E. C. Bain, research metallurgist, Atlas Steel Corp., Dunkirk, N. Y.

*The Hardening of Steel,*** by Dr. Zay Jeffries and R. S. Archer, Research Bureau, Aluminum Co. of America, was presented by Mr. Archer.

Crystallization of Iron and Its Alloys, by Professor Albert Sauveur, professor of metallurgy, Harvard University, was presented by title.

Experiments on the Effect of Temperature on the Impact Resistance of a Low-Carbon Steel Which Has Been Worked or

*Published in September, 1923, Transactions, page 353.
**Published in September, 1923, Transactions, page 263.

Deformed at Different Temperatures by N. Richardson and E. K. MacNutt, Watertown Arsenal Metallurgical Laboratory, was presented by title.

At 2:30 p. m. the Hardness Testing Symposium under the auspices of the National Research Council and the chairmanship of A. E. Bellis, was held in the meeting room at Motor Square Garden. The following papers were presented. All but the first one was published in the September issue of TRANSACTIONS:

The Herbert Pendulum Hardness Tester—E. G. Herbert, England.

The Hardness of "Common High" Sheet Brass—A. L. Davis, metallurgist, Scovill Mfg. Co., Waterbury, Conn.

Magnetic Indications of Hardness and Brittleness—A. V. deForest, Research department, American Chain Co., Bridgeport, Conn.

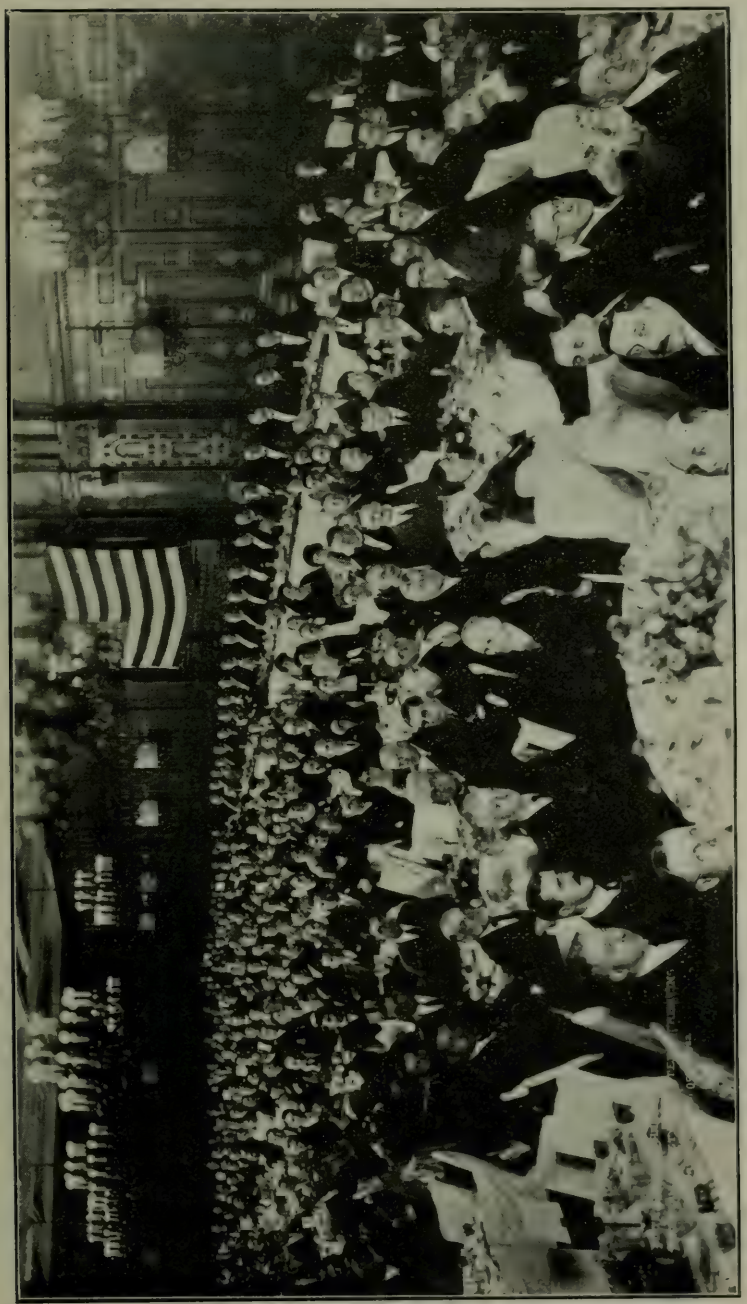
Testing of Steel for Hardness—H. M. German, metallurgist, Henry Disston & Sons, Inc., Philadelphia.

The exposition closed at 5:30 p. m. and the annual banquet of the Society was held during the evening in the English room of the Fort Pitt Hotel. This banquet was exceedingly well attended as evidenced by the accompanying photograph. At the speaker's table were seated the officers and guests of honor of the Society including Governor Gifford Pinchot and Captain Irving H. O'Hay. After the dinner had been served President Lynch opened the meeting with a few remarks and then introduced each of the newly elected officers.

PRESENTATION OF THE FIRST HENRY MARION HOWE MEDAL TO MRS. HOWE

President Lynch made the following remarks in presenting the first medal to the Society's honored guest, Mrs. Henry Marion Howe, widow of our esteemed and beloved Honorary member, Doctor Henry Marion Howe:

"The Board of Directors of the American Society for Steel Treating realize that man needs special incentive to develop and prepare for publication new and useful ideas. They also realize that one of the best incentives for this type of work is something that brings to an author recognition and honor. They have, therefore, made provision for an honor gold medal to be known as the



Fifth Annual Banquet of the American Society for Steel Treating, English Room, Fort Pitt Hotel, Oct. 11, 1923

Henry Marion Howe Medal. This medal is to be awarded to the author of the paper which shall be judged to be of the highest merit.

"All papers in order to be considered must be published originally in the TRANSACTIONS of the Society, during the twelve months ending August 1 of each year in which the medal is awarded.

"The competition for the Henry Marion Howe Medal shall be open to all. The award shall be made by the Board of Directors. The award may be withheld at the discretion of the Board of Directors.

"Dr. Henry Marion Howe in whose honor this medal is given was a son of a noted physician of research type who was also a great philanthropist. His mother, Julia Ward Howe, was a leader in the abolition of slavery and is perhaps best known to the American people as the author of the *Battle Hymn of the Republic*.

"Dr. Howe was so well known and received degrees and honors from so many and varied sources that it is only possible to mention a few.

Elliott Cresson Gold Medal, Franklin Institute—1895.

Bessemer Medal, British Iron and Steel Institute—1895.

Chevalier Legion d'Honneur of France—1900.

Knight of Stanislas, Russia—1906.

John Fritz Medal—1917.

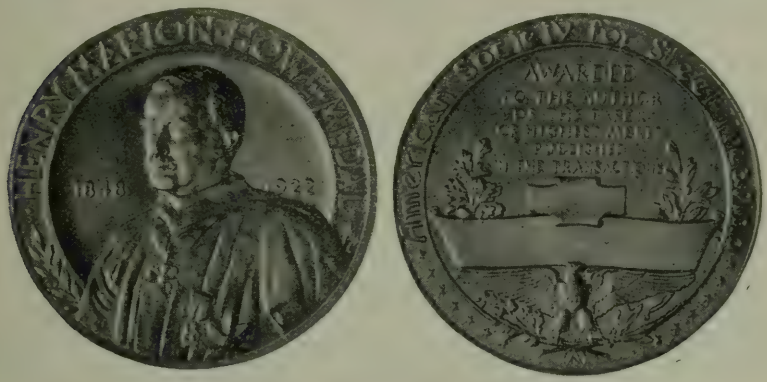
"He was widely known through his scientific books and technical papers today universally accepted as text books, a constant attendant at our meetings and his contributions to the discussions were always timely and stimulating. He was a master in presiding over and directing meetings—in expressing his thoughts in simple, forceful language—a man of keen vision and power of observation—a friend and an inspiration to all who knew him.

"On behalf of the Board of Directors, I have the honor of presenting the first medal, struck in bronze, from the die from which the gold medal is made to Mrs. Henry Marion Howe, who

was recognized by Dr. Howe as an inspiration and co-worker, and who always accompanied him in his travels in this country and abroad.

PRESENTATION OF THE HENRY M. HOWE MEDAL TO MR. JANITZKY

"On behalf of the Board of Directors, I have the honor of presenting the first Henry Marion Howe Gold Medal for 1922 to Emanuel J. Janitzky for his paper, entitled, the *Influence of Mass in Heat Treatment.*"



The Henry Marion Howe Medal*

The meeting was then turned over to the toastmaster, George H. Neilson, who presented the awards to those school children contestants who had won honors in the recent essay writing contest conducted by the Pittsburgh Post and the American Society for Steel Treating, pertaining to the steel industry of Pittsburgh.

Toastmaster Neilson then introduced the speaker of the evening, Captain Irving H. O'Hay, hero of many wars and the hero of Richard Harding Davis' novel, "The Soldier of Fortune." Captain O'Hay served in the World war with the "Princess Pats" and later with the American Expeditionary forces. Captain O'Hay gave a wonderfully interesting talk upon his adventures around the world, combining humor and wit with facts and conditions of life as he finds them.

Governor Pinchot having arrived later in the evening was

*The Society wishes to acknowledge the valuable courtesy of R. Wallace and Sons Manufacturing Co., of Wallingford, Conn., for the designing and striking of the Henry Marion Howe Medal, and to the Keller Mechanical Engineering Corp. of Brooklyn for the preparation of the model and the cutting of the dies.

then introduced and gave a brief address pertaining largely to the political situations in the state of Pennsylvania.

W. H. Eisenman, national secretary of the American Society for Steel Treating then extended words of appreciation and thanks to the various Convention committees and to the entire membership for their loyal support in making the Fifth Annual Convention a success. In closing he announced the presentation of a medal to be known as the Past-President's Medal to the retiring president, Tillman Danis Lynch.

The meeting adjourned at 11:30 p. m.

Friday, Oct. 12

The Friday morning technical session was held at 9:30 in the Ball room of the William Penn Hotel, Dr. Paul D. Merica, being chairman of this session. The technical papers program for this session was as follows:

Carbon and Carbon-Vanadium Steel Castings—A Comparsion —J. M. Lessells, mechanical engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Investigation of the Treatment of Steel for Permanent Magnets—R. L. Dowdell, Instructor in Metallography, University of Minnesota, Minneapolis.

Protective Coatings for Selective Carburization—J. S. Vanick and H. K. Herschman, metallurgist and assistant physicist, Bureau of Standards, Washington.*

The Physical Properties of Metals at Elevated Temperatures —Vincent T. Malcolm, metallurgist, Chapman Valve Mfg. Co., Indian Orchard, Mass.

The Seasoning of Steel—W. P. Wood, Department of Metallurgy, University of Michigan, Ann Arbor, Mich.**

Conical Illumination in Metallography—H. S. George, Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y.†

The Theory in Quenching Steels—Kotaro Honda, Tohoku Imperial University, Sendai, Japan. (Presented by title.)††

At 2 p. m., the Symposium on Metallurgical Education was

*Published in September, 1923, TRANSACTIONS, page 305.
**Published in October, 1923, TRANSACTIONS, page 488.
†Published in August, 1923, TRANSACTIONS, page 140.
††Published in October, 1923, TRANSACTIONS, page 450.

held in the meeting room at Motor Square Garden under the chairmanship of Professor S. L. Goodale. Considerable interest has been shown in this annual symposium and it is felt that as evidenced by this interest it is a session which should be fostered and held each year during the Annual Convention.

At 4:30 p. m. Committee A-4 of the American Society for

A Booth on the Main Floor of Motor Square Garden
(Courtesy of *Iron Trade Review*)

Testing Materials under the chairmanship of Professor H. M. Boylston held a meeting at Motor Square Garden.

At 10 p. m. the exposition officially closed.

Plant Visitation

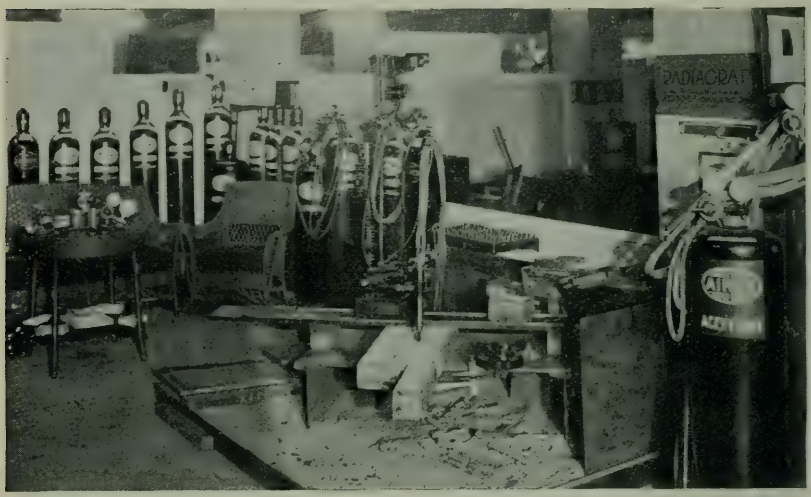
Many members and guests availed themselves of the opportunity of visiting various plants in and around Pittsburgh. The plants which were officially scheduled for visitation were the Westinghouse Electric & Mfg. Co. on Tuesday afternoon, the Homestead Works of the Carnegie Steel Co. on Wednesday afternoon and the National Tube Works, McKeesport, Pa., on Friday afternoon. All of these plant visitations were very well attended and proved of great interest to those who had the privilege of attending.

Visiting Ladies Entertainment

The visiting ladies were royally entertained by the Pittsburgh

Entertainment committee under the chairmanship of J. A. Succop, and the ladies auxiliary committee and they enjoyed many hours of sight-seeing in and around Pittsburgh.

The ladies registered immediately upon their arrival in Pittsburgh for the purpose of indicating those activities in which they desired to participate. The first activity was a luncheon served



A Booth on the Sub Floor of Motor Square Garden
(Courtesy of *Iron Trade Review*)

on Monday, Oct. 8 at 1 p. m. in the Blue Room of the William Penn Hotel. This was followed by an auto ride through the city. In the evening the ladies visited the exposition at Motor Square Garden. Tuesday afternoon the ladies were entertained at a tea at the Margaret Morrison Home, Carnegie Institute. In the evening they were entertained at a theater party. Wednesday morning at 10:00 the ladies visited the H. J. Heinz Company's pickle factory and after exploring the factory had luncheon there. Wednesday evening they attended the annual dance of the Society in the Ball Room of the William Penn Hotel. Thursday afternoon was devoted to a reception to Mrs. Henry Marion Howe, while in the evening they attended the annual banquet of the Society which was held at the Fort Pitt Hotel.

From all reports the ladies had a most enjoyable time throughout the week.

THE PRESIDENT'S ANNUAL ADDRESS

TILLMAN DANIS LYNCH

Introduction

The American Society for Steel Treating has added another year of progress to its history. Its accomplishments are not all that we could wish, but as we must learn by experience, we trust that our shortcomings may be a signal and our achievements an inspiration for a higher and nobler plane of activities.

Our society's goal is worthwhile, its field of activity is unique and it has a very important task to perform by combining our thoughts and experiences for the advancement of not only our membership but to serve mankind.

Let us review briefly the activities of the year. These activities are effective through our chapters, our committees, our national board and the TRANSACTIONS. Our chapter meetings give us the personal work and individual contact which results in co-ordinated efforts. Our committees are instruments for bringing into more constructive and definite form such general information, recommended practices and standards as will assist our membership, advance our organization and establish permanently the work that is accomplished.

Membership

Our membership continues to grow, as is shown by our National Secretary's report with 18.7 per cent increase for the year.

It has been the purpose and policy of the directors to recognize in our membership only those who take some part in the Society's activities, at least that of assisting in its support. This membership list is, therefore, a real one, including only those who are in good standing or whose dues are in no case more than 3 months in arrears.

Chapters

Our chapters are 28 in number, the same as last year. The chapter at Bridgeport, Conn., has been discontinued and a new

one has been organized at Los Angeles, Cal. Reports from this new chapter are very encouraging and its members are showing a healthy active spirit.

The chapters, in general, are demonstrating the good that comes to our members from personal contact, exchange of ideas and experience and the work accomplished by each chapter and its members is in direct proportion to the activity of its members in taking advantage of the opportunities thus afforded to discuss both the personal and general problems taken up.

In former years, the president visited all chapters, but this year a different plan was tried out, viz., each member of the Board of Directors was assigned two or more chapters to visit officially and to make a written report to the Board. These reports give the personnel, financial condition and activities of the various chapters.

It is estimated that the attendance at our chapters for the year has been more than 20,000—a good demonstration of the opportunity given to our members and friends to profit by the exchange of ideas.

Sectional Meetings

There have been two sectional meetings held during the year, one with the Chicago chapter in February and the other with the Lehigh Valley chapter in June. The programs for these two meetings were prepared by the respective chapters and the papers presented were of the highest type. Visits were made to local manufacturing plants where members were shown special courtesies. These meetings brought together many men from different chapters and especially those members located nearest the chapter where these meetings were held, who would not otherwise have been brought together; and the great interest shown, indicates that these sectional meetings should be continued.

It has become apparent however that some of the smaller chapters have refrained from having sectional meetings held in their locality on account of the added cost of such a meeting to the chapter. The Board has therefore decided that the national office should provide for the expense incidental to

the holding of at least two sectional meetings each year and it is hoped that no chapter will refrain from entertaining a sectional meeting on account of the cost.

Committees

Some of our National committees have done splendid work while others have not been especially active. The Standards committee is an example of one that has done a real work.

The planning of this committee was a little different from that of former years.

The main membership was made up of a general chairman and four members. Each member was made chairman of a sub-committee on recommended practices of an assigned subject. These sub committees were localized in limited zones to enable them to get together as separate working committees.

Sub-Committee I—Treatment of Tool Steel—W. J. Merten, Chairman, was located in the Pittsburgh district. Their report is published in September, 1923, TRANSACTIONS and is real evidence of work done.

Sub-Committee II—Treatment of Steels General (not including Tool Steel)—F. E. McCleary, Chairman, located in Detroit district. A progress report is made.

Sub-Committee III—Case Hardening—R. J. Allen, Chairman, located in New England. A progress report is made.

Sub-Committee IV—Pyrometry—J. H. G. Williams, Chairman, located in Philadelphia district. This report is published in September, 1923, TRANSACTIONS and includes "Notes on Thermoelectric Pyrometers and Instructions for Their Use in Heat Treating Steel." The data given in this document is beyond doubt the most thorough and comprehensive so far in print, and this society may well be proud to have fostered its production.

Finance Committee

The Finance committee has, during the past year, exercised general supervision over the financial policies of the society. It supervised the closing of the books for the fiscal year of 1922 and recommended to the Board of Directors suitable

charges to be made for depreciation and bad debts. It made recommendations as to the amount and investment of the various reserves of the society which were in general approved by the board. It recommended and upon approval by the board put into effect a more equitable distribution of office expenses.

The committee caused the books of the Secretary and Treasurer to be audited by a certified public accountant, a copy of their certificate being published in the May, 1923, TRANSACTIONS.

It prepared a budget for the year 1923 which, after minor changes, was approved by the Board of Directors. The committee gave careful supervision over the operation of the budget which has been adhered to within very close limits.

This committee, as you will note, has given its efforts to providing solidarity and security of our funds.

Constitution and By-Laws Committee

The constitution and by-laws committee was commissioned by the Board of Directors to revise and rewrite the constitution and by-laws of the society. This committee has given much time and painstaking thought to this work, resulting in a rewritten document. The entire Board gave a full day to its consideration section by section before ordering it to be printed and sent to the membership in a tentative form for their comments and constructive criticisms. It is hoped that the membership at large will render all possible assistance in making this document just what it should be. Mr. Havens, the chairman of the committee, will make a progress report at this convention.

The Board of Directors has held five meetings during the year 1922-1923, the first at Detroit at the close of the convention to talk over the general plans for the year; and the second at the national office, Cleveland, Ohio, on Oct. 27 at which time the eight standing committees and four sub-committees were appointed.

A number of committees have been appointed during the year to co-operate with other organizations, namely National Research Council, Division of Engineering, War Department, United States Army, Advisory, Bureau of Standards, Bureau of

Mines, Drill Steel Investigation, On Nomenclature with American Society for Testing Materials, Society of Automotive Engineers, Sub-Committee XIV of Committee A-1-American Society for Testing Materials on Tool Steel, National Research Council, Instrument Manufacturers and Users.

The third meeting was held at Chicago on Feb. 9 during the sectional meeting; the fourth meeting at Bethlehem on June 16 during the sectional meeting and the fifth at Pittsburgh during the convention.

These meetings have been scheduled so as to accomplish the greatest benefits for the good of the society with the least amount of time and mileage.

All members of the Board have been in attendance at each of these meetings.

Transactions

Our TRANSACTIONS have continued to improve under the supervision of our editor—Ray T. Bayless, and the Publication committee of which Prof. H. M. Boylston is chairman.

They are striving continually to improve the tone of TRANSACTIONS by being more and more exacting in the question of acceptance of manuscripts.

Our Editor has devised a scheme of trimming cuts so as to reduce the cost of publishing without interfering with the proper illustration of the paper.

Each issue includes one or more editorials on general affairs of interest to our members.

Beginning with the July, 1923 issue, a new style of type page has been used which is a very marked improvement.

Our TRANSACTIONS is now recognized as one of the best if not the best publication of its kind. The papers published in recent issues and being presented at the convention represent the rapid progress that is being made and provide for our membership an encyclopedia of up-to-the-minute refinements in the art and science of heat treating metals.

Data Sheets

The problem of preparing data sheets has been given much thought. The National Secretary's report will show the progress made.

Annual Convention

The annual convention and exposition at Detroit last October set up a standard that will be difficult to excel. The *Iron Age* gave expression in their issue following the convention which expresses the general opinion most admirably, namely: "An unqualified success was the general verdict of those who attended the fourth annual convention and exposition of the A. S. S. T. The record made by the society, only three years old, both in technical papers and in exhibits, insures it a place among the leading technical organizations in the country and stamps its annual meeting as one to be looked forward to and to be reckoned with."

The Pittsburgh Convention is now a reality, it is 100 per cent educational and it has drawn its papers from among the best talent in this country and also from England, France and Japan.

The Pittsburgh Exposition covers 33 per cent greater floor area than any previous exhibition and the quality and character of the exhibits were never better. We are advised that this is the first time that both floors of Motor Square Garden have been fully occupied. The Board of Directors has made a change, this year, in the method of financing the convention. The exhibition has been planned on a self-sustaining basis and an entertainment fund has been provided from the rental receipts so that special donations from local chapters will not be necessary. This plan has in general been carried out by our National Secretary assisted by the local committees.

The chairman of our local convention committee has instituted a feature that is worthy of special mention. He has arranged for each member of the Pittsburgh chapter to wear a badge with the words "AT YOUR SERVICE" printed thereon. Let this emblem remind us that we should all help to conduct the affairs of this organization so that through us, it may fulfill the law of service. May we each be mindful of the fact that we are put upon this earth to be of service to each other and to work out the great plan of life. God never made a loaf of bread, but he made man, a field, and gave us seeds to sow.

God never made a coat, but he gave us the sheep to grow wool and the art of spinning and weaving.

God never made steel, but he gave us iron ore, limestone and coal.

These raw products are ours to use and steel is ours to heat treat according to the laws so natural and so definite.

What are we doing as individuals and as an organization to be of real service in working out the great plan of which we form a part? Let our efforts be co-ordinated with the efforts of others so that we may continue to be of service one to the other and all to the fulfillment of this plan.

Conclusion

In concluding this term of office, as your President, I desire to express my appreciation for the support so freely and effectively given by our members at large, our committees, our chapters and our Board of Directors. All have given much of their time and talent to the affairs of the society. Last but not least, I appreciate the loyal and untiring efforts of our staff whose full time is devoted to the society work and which has made it possible to carry on not only the extensive work at the national office but to edit and publish our TRANSACTIONS and carry on so successfully the big task of managing, in conjunction with our local committees, our annual convention and exhibition.

It is only by the united efforts of all, guided by the special efforts of your officers and directors elected to serve you that our society can continue its growth and high standing among the national associations.

ANNUAL REPORT OF THE SECRETARY

WILLIAM HUNT EISENMAN

The Secretary is pleased to present his annual report which will show that the American Society for Steel Treating has had another successful year.

The majority of members of the American Society for Steel Treating measure true value not by what they get, but by the service they are able to give, and they are all happy at the opportunity of sharing their success with others. They find the greatest satisfaction in knowing they have been of service to the society and to other members. Many nonmembers are perfectly well satisfied to enjoy the benefits provided for them by others and are unwilling to do any part in elevating or maintaining the standard of a profession in which they are engaged. It may be true of some, but fortunately not of many, that they have no ambition for personal advancement and care little about increasing their own efficiency or in the development of the arts and sciences for which the society stands.

Meetings

The sectional and annual meetings of the society continue to grow in importance and usefulness. The Chicago sectional meeting showed a registration of nearly 200, and the sectional meeting at Bethlehem showed a healthy registration of 167 members, while the registration at the annual convention at Detroit last year represented over 40 per cent of the membership and was recognized at that time as being unparalleled in the history of American technical societies, that such a large percentage of the members should be enrolled as being present at a national convention. The meetings of the local chapters have continued to grow in importance and in general benefits to the membership and to increase the prestige of the local and national society.

Too much credit cannot be given to those individuals who have presented papers before the various chapters, sectional and annual meetings, for the large amount of work and effort that have been necessary to properly present their subject to the technical and the nontechnical members present.

Probably the larger percentage of those in attendance at the

chapter meetings are not members of the society, as is shown by the fact that in the 226 meetings held last year the attendance has been in the neighborhood of 23,000. While there are no accurate figures on the percentage of visitors at these meetings, nevertheless, it is a conservative estimate that probably 40 per cent represent men who are interested in the American Society for Steel Treating but not members of the society. Nevertheless, the various chapters have made it a point to extend a cordial welcome to those nonmembers present because it is realized that they are the seeds for future growth in our membership.

Memberships

On the recommendation of the delegates at their annual meeting at Detroit last year the national officers arranged a membership and attendance contest between the chapters of the society.

The membership and attendance contest closed on June 30, 1923 with the following results:

First Prize	$200.00	Tri City	127.6 per cent
Second Prize	150.00	South Bend	99.3 per cent
Third Prize	100.00	New Haven	85.8 per cent
Fourth Prize	50.00	Cincinnati	65.5 per cent

The nearest to Cincinnati was the Northwest chapter with 56.4 per cent and Syracuse with 55.5 per cent.

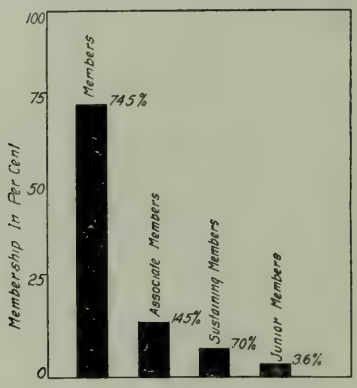
It was quite evident from the number of chapters participating in the contest and the results obtained that it was very interesing and helpful. However, as the contest progressed it was observed that the smaller chapters had a certain advantage over the larger chapters, inasmuch as they required a smaller number not only of new members but of those in attendance at meetings to give a higher percentage.

There are at the present time in the American Society for Steel Treating 2746 members of which 2048 or 74.5 per cent are of the member classification; 400 or 14.5 per cent are associate members; 191 or 7 per cent represent sustaining memberships; while 99 or 3.6 per cent represent junior memberships. There are 6 honorary and two founder members.

Membership in the society during the period from September 1922 to September 1923 showed a gain of 18.75 per cent. On Sept. 1 of last year there were 2313 members. During the year

there has been a net gain of 433 members so that the total membership on Sept. 1, 1923 of bona fide paid-up members is 2746.

There is an excellent opportunity for additional and valuable work to be done in increasing the number of junior members in the society. This work did not start with any effectiveness until the year of 1922 and at the present time is showing gradual improvement. The larger portion of the junior members was secured during the fall of 1922 and spring of 1923. Inasmuch



Graphical Representation of Membership as of Sept. 1, 1923.

as the dues are but $2.50 for the junior members and entitles them to receive the publications of the society and attend chapter meetings, it is a very valuable proposition for the junior and secures his present and future interest in the society.

It is interesting to note that during 1922 and 1923 136 of the 191 sustaining members were added to the list. This was the result of action by the board of directors whereby all but $6.50 of the dues of the sustaining member is returned to the local chapter, so that the sustaining member of a local chapter becomes in reality what the name suggests and they assist materially in financing the chapter programs, and thus have aided greatly in placing many chapters in a better financial position.

About 300 members of the society are serving on more than forty technical and administrating committees in the preparation of standards, reports, professional papers, meetings, research work and the dissemination of literature for the advancement of the

metallurgical profession and the steel industry. Of this number about one-half are on national committees and the other half serving on local committees. The ready response of the entire membership to notices of appointment on various committees as well as their acceptance of the additional obligations and duties entailed, explains one of the reasons for the remarkable success of the American Society for Steel Treating. The membership as a whole is more than willing to do its share of work and to contribute, so far as the individual's abilities permit, in furthering the worthy aims and purposes of the organization.

Publications

Probably the greatest advancement in any publication representing a technical society made in any one year was in the TRANSACTIONS of the American Society for Steel Treating. This has

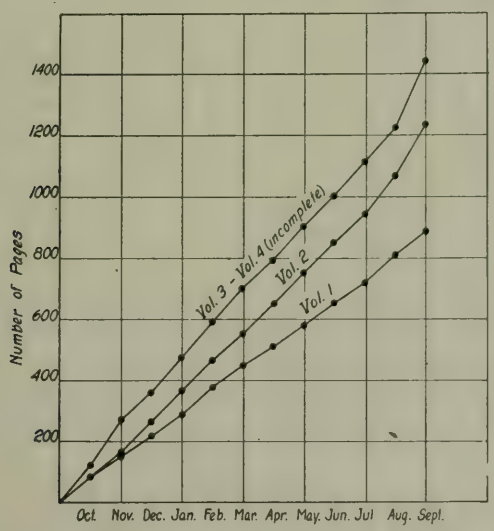


Chart Showing the Progress Made in the Number of Editorial Pages in TRANSACTIONS

been due entirely to the efficient efforts of R. T. Bayless, editor, and the publication committee under the able chairmanship of Professor H. M. Boylston. The size of the type page as well as the spacing between lines have been changed in order to give the TRANSACTIONS a better appearance and greater readability. At the same

time more careful attention has been given to the redrawing of charts and arrangement of material in the adoption of a standard style, so that the publication is regarded with most favorable consideration. There is one file in National headquarters that contains countless letters of commendation and congratulations upon the high position the TRANSACTIONS has taken both in the make-up and contents under the capable direction of Mr. Bayless.

Beginning with Volume I of the TRANSACTIONS there has been published during the three years of its existence 3424 editorial pages of material of interest to the membership or, an average of about 1141 pages per year. Volume I of the TRANSACTIONS contained in twelve issues 840 pages; Volume 2, twelve issues 1238 pages; Volume 3, nine issues 1000 pages, and the three numbers of Volume 4 so far published contain 446 pages. For convenience of handling and reference it became necessary to issue the TRANSACTIONS in two volumes a year rather than one, as the one volume would contain in the neighborhood of 1500 pages which makes it undesirable for binding purposes as well as for ready reference. Consequently, beginning with the July, 1923 issue, Volume 4 was started, this closes with the December 1923 issue. It is probable that about 1000 pages of editorial matter will be printed and ready at that time for binding in Volume 4. Thereafter each volume will include six numbers of the TRANSACTIONS.

During the same period as covered by Volume 1 and Volume 2 there was published in the 1923 TRANSACTIONS 1446 pages of reading matter or an increase of 17 per cent over that published last year. This increase in volume of printed matter, increased labor and expense in the preparation of the same, but it is believed as most frequently stated that the TRANSACTIONS alone is sufficient to repay an individual for his membership in the society.

Data Sheets

Progress is being made in the preparation of data sheets for the handbook, through the national office.

The board of directors has decided that all data sheets shall be passed by the Standards committee before being sent to the members.

While this work entails a large amount of detail it nevertheless is making satisfactory progress and it is the hope and expectation

of your secretary that within the period of two months after the close of this convention the first sets of data sheets will have been approved by the Standards committee of the American Society for Steel Treating and be ready for the use of the membership.

The Standards committee has already decided that the sheets are to be LeFax size, so binders in several grades are available to the membership at cost. After the first series of data sheets are out, it is then expected that data sheets will be forwarded to those members in good standing at least three or four times a year.

The method for the compilation of the society handbook has been somewhat changed from the plan originally announced, and it is now to be a composite work of all of the members of the American Society for Steel Treating. Each member will receive credit in the handbook for the data sheets he prepares and presents.

The list of data sheets given below has already been suggested and material has been submitted upon the larger portion of the list. However, the submitted material is first forwarded to a number of members of the society who are familiar with the subject under consideration and after their comments and criticisms have been returned, proper notation and revision of the material is made according to the constructive criticisms and suggestions received. The material is then *again* submitted to another group of members interested in the subject. The second revision is then submitted to the Standards committee of the American Society for Steel Treating. After approval by the Standards committee it is to be printed and forwarded for use by the members.

There will be included in the first set of data sheets the report of Subcommittee I of the Standards committee, on "Recommended Practice in the Heat Treatment of Plain Carbon Tool Steel," and "Recommended Practice in the Heat Treatment of 18 per cent Tungsten High Speed Steel," as well as the report of Subcommittee IV, dealing with "Thermoelectric Pyrometers and Instructions for their Use in Heat Treating Steel."

The subjects upon which data sheets are being prepared, in which either the material is at present available, or in preparation follows:

Influence of Nickel
Influence of Vanadium

Influence of Tungsten
Influence of Uranium
Influence of Molybdenum
Influence of Chromium and Manganese
Influence of Silicon
Blue Brittleness
Etching Solutions to Be Used and Structure Revealed by Each
Etching Solutions and Their Preparation
Specific Heat of Air
Iron and Steel Metallurgy in Brief
Standard Shapes and sizes of Firebrick
Phase Rule
Forging Temperatures
Fuel and Energy Loss of Furnace Walls
Equivalent Quantity of Fuel Based on Heat Values
Characteristics of Various Gases
Nitrogen in Steel
X-ray Investigations
Gases in Metals
Deep Acid Etching
Salt Baths
Temperatures Judged by Colors
Fuel Areas for Furnaces
Comparative Costs of Various Fuels on B.t.u. Basis
Specific Heat of Iron and Steel
Melting Points Sodium and Potassium Nitrate
Thermal Conductivity of Insulating and Refractory Material
Temperature Conversion Table
Table for Carburizing and Heat Treatment of Carburized Steel
Iron Carbon Critical Range Diagram
Temperature Color Charts
Brinell Hardness Numbers
Critical Range Diagram for Iron Carbon Alloys
Volume Weight Tables Carbon and High-Speed Steel
Tempering Table
Ghost Lines
Effect of Size and Mass on Physical Properties
Alpha Beta and Gamma Iron

Use and Care of Pyrometer
Lead Baths
Strength of Steels at High Temperatures
Transfer of Heat
Hardness of Carbon-Manganese Steel
Physical Properties of Alloy Steel
Cutting Tests on High-Speed Steel
Recommended Heat Treatment of Plain Carbon Tool Steel
Recommended Heat Treatment of 18 per cent Tungsten High-Speed Steel
Hardness of 1 per cent Carbon Tool Steel
Physical Properties of Carbon Steel

Special Services

Many of the members of the American Society for Steel Treating have availed themselves of the opportunity to secure reprints of articles as well as translations of papers appearing in foreign and local publications through the national office. While the demand has not reached enormous proportions it is, nevertheless, of sufficient strength to indicate that the membership appreciates quite thoroughly having this service available.

The employment bureau which functions through the National office is still of great benefit to the membership and has been successful during the past year in placing many of the members in contact with desirable openings as well as securing for employers men satisfactory to their needs.

About 250 members availed themselves of the offer of the national office to secure TRANSACTIONS binding for them at the cost of the work, and in that way they have been able to have their volumes bound uniformly each year at a minimum of expense and effort.

The staff of the national office consists of the editor of the TRANSACTIONS, a bookkeeper, two stenographers and a membership file clerk.

Some idea of the work involved may be gathered from the statement that over 100,000 pieces of mail matter leave the office annually not including the copies of the TRANSACTIONS which add a total of 36,000 more pieces. No effort has been made to work short-handed because it is realized that the service of the national

organization is one of the important requisites of the society. We are quite confident that the report of the National Treasurer showing how the activities of the society have been conducted with increasing success from a financial standpoint is gratifying and encouraging. It is interesting further to note that the advertising revenue from the TRANSACTIONS has been increased during the year.

The exposition has made rapid progress and this year is 50 per cent larger than the one at Detroit last year. It is recognized as one of the principal annual events in the iron and steel industry.

The advancement the society has been able to make in the three years of its organization is indeed a point of just pride with the entire membership, and so far exceeds their fondest hopes and expectations that they view with pleasure the fact that the society has so rapidly taken front rank in the industry it represents. This rapid and commendable progress is the result of the united energies, both moral and financial, of all its members. The American Society for Steel Treating will not permit self-satisfaction to be its motto, but will always continue to be the synonym for Advance, Efficiency and Service.

CORROSION IN MINE WATERS, AND RECENT INVESTIGATIONS OF IT BY THE U. S. BUREAU OF MINES*

By Robert J. Anderson and George M. Enos

Abstract

This paper discusses the problem of corrosion in a general way, especially as applied to the corrosion of metals and alloys in acid mine waters. The several theories of corrosion are discussed and it is pointed out that these do not explain the fundamental cause for corrosion.

Total immersion tests have been made on a large number of irons and steels for corrosion in acid mine water, and it has been shown that this corrosion is much different from that occurring in air. The results and photomicrographs of long-time immersion tests which have been made on some 45 metals and alloys are incorporated in this paper.

An accelerated electrolytic corrosion test apparatus is described.

Introduction

DURING the past several years, investigation has been carried on by the U. S. Bureau of Mines on the corrosion of metals and alloys in acid mine waters of coal mines in the western Pennsylvania coal region, and the object of the present paper is to discuss briefly the corrosion problem in a general way, and to direct attention to certain of the results obtained in tests on the corrosion of metals and alloys in acid waters from coal mines. Numerous other investigations on corrosion have been carried out in the past by the bureau, but these need not be taken up here. The work discussed in this paper has been carried out in co-operation with the Carnegie Institute of Technology, Pittsburgh, Pa., under a co-operative arrangement with the coal-mining industry of

*Published by permission of the Director, U. S. Bureau of Mines.

This paper is an abstract of a lecture given before the Pittsburgh chapter of the society. Of the althors, Robert J. Anderson is metallurgist and George M. Enos is junior metallurgist, both of U. S. Bureau of Mines, Experiment Station, Pittsburgh, Pa.

western Pennsylvania. Samples of metals and alloys for test have been very kindly supplied by industrial firms. The work has been under the general supervision of A. C. Fieldner, superintendent and supervising chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

It is well known that the search for alloys that will withstand corrosion influences is one of the most energetically explored fields of physical metallurgy, but so far experimental work has been on an empirical basis solely, and notably good results are quite accidental. In selecting alloys for use as engineering materials of construction in structures where particularly corrosive atmospheres or solutions must be withstood, it is necessary to consider not only the resistance to corrosion of the materials under the specific conditions of employment but also their physical properties, ease of fabrication or casting, and cost. The latter items are often overlooked by those working on the development of corrosion-resisting alloys. The corrosion of alloys in acid mine water is a typical example of the failure of engineering materials under attack by corrosive solutions, and in selecting alloys for use in pumping equipment for mines, one of the most important properties for consideration is the corrodibility of the materials.

Water from coal mines is usually decidedly acid and causes considerable trouble and expense to operators because of its corrosive action on mine equipment. Water from metal mines is also frequently corrosive, e.g., that of the Montana copper mines. Underground waters in coal mines are acid from the presence of free sulphuric acid and sulphates of iron and aluminum, and such waters will readily corrode ordinary ferrous and nonferrous materials.

The object of the recent work of the bureau has been to investigate the corrosion of commercial metals and alloys by acid mine waters, and certain of the work has been published. Thus, W. A. Selvig* and one of writers[14] have investigated the comparative corrosion losses of 45 metals and alloys on immersion in acid mine waters, and the writers [18] have studied the microscopic features of these corroded materials.

*Numbers refer to bibliography appended to this paper.

Most recently, study has been made by the writers and J. R. Adams (research fellow of the Carnegie Institute of Technology) on the fundamentals of corrosion, corrosion theories, and the development of an accelerated test for corrosion. The results of this work will be published later. It may be added that in the selection of alloys for withstanding corrosive conditions it is necessary that the selection be based on reliable and adequate tests, and so far no standard method for corrosion testing has been developed. For examining the relative corrodibility of different metals and alloys in solutions, the most satisfactory test has been the long-time immersion test, but this has the decided disadvantage of consuming considerable time.

The corrosion of metals and alloys in specific corroding media like mineral acids, sea water, fresh waters, salt solutions, atmospheric air, and gases has been studied in detail for many years, but it is only recently that systematic investigation has been undertaken on the corrosion of materials in acid waters from coal mines. At present the corrosion of pump parts (rods, valves, etc.) by acid mine waters in the western Pennsylvania coal region is very serious, and it should be added that rails, rolling stock, tools, and other equipment corrode when exposed to the action of acid waters. The work of the bureau on corrosion in mine waters has been carried out specifically with a view of procuring data that might help in the solution of the difficulties experienced by mine operators. Though no data are available as to the monetary values of the losses incurred through the corrosion of equipment in mines, the total is considerable. Moreover, additional financial loss is occasioned by shutdowns and repairs required, e.g., in the stopping of a pump. Hadfield[15] has recently estimated the annual cost of wastage due to rusting of the world's iron and steel as over $3,500,000,000 and no argument is needed to show that anything which can be done to reduce losses here and there in specific cases is worth while.

Theoretical Aspects of the Corrosion Problem

Any discussion of the corrosion problem would be incomplete without at least brief reference to the present status of the theory. A number of different theories have been

advanced to explain the cause of corrosion inception and the mechanism of corrosion processes, but no one of these is satisfactory to account for the initiation of corrosion or to explain the mechanism of all observed cases of corrosion. There certainly can be no fundamental difference in the mechanism of corrosion inception under any conditions, and one of the objects of recent work in the bureau has been to study the fundamentals of corrosion with a view to determining if there could be one explanation underlying all the phenomena observed.

Corrosion is generally regarded as the result of the tendency which a metal has for forming oxides or salts when in contact with a liquid or gas medium, and of the many theories which have been advanced to explain the mechanism of the phenomenon, the electrolytic, acid, and direct oxidation theories have been supported most strongly. The main theories which have been advanced to account for corrosion include the following: (1) simple oxide (or direct oxidation) theory; (2) acid theory; (3) electrolytic theory; (4) auto-colloidal catalytic theory; (5) hydrogen-peroxide theory; (6) adsorption theory; and (7) biological theory. These are briefly discussed below.

Simple Oxide Theory

The simple oxide, or direct oxidation, theory was the first of the modern corrosion hypotheses. This theory has been supported by a number of workers as being exclusively applicable, and some investigators[11] have recently taken the position that some corrosion processes can be explained on the basis of direct oxidation. The theory assumes that a metal is attacked chemically by oxygen or other gas without previously passing into solution, but this is negated by proponents of the electrolytic and acid theories on the basis that liquid water is necessary for corrosion in addition to oxygen.

Acid Theory

The acid theory assumes that in addition to oxygen and water, some acid must be present before corrosion can take

place, and a weak acid like carbonic acid is sufficient. The process of corrosion is cyclical. This theory has been strongly supported, particularly by Friend,[10] but it may be regarded as an electrolytic theory not necessarily expressed in terms of the ionic hypothesis.

Electrolytic Theory

The electrolytic theory considers corrosion to be electrochemical in nature, and according to this, water being an electrolyte and therefore ionized to a small extent to hydrogen and hydroxyl ions, it is not necessary that an acid be present. When a metal is placed in water, or when a metal is under such conditions that a film of water is upon it, the metal tends to dissolve in the water, i.e., it tends to pass from the atomic (metallic) state to the ionic state. As an atom of metal passes into the water, it assumes a positive charge of electricity, leaving the metal mass from which it departed charged negatively. The tendency for a metal to dissolve thus in an electrolytic, is termed its solution pressure, and the result of this tendency is corrosion. This theory was advanced by Whitney[1] and receives general acceptance at the present time. This theory has been termed electrolytic in contrast with the acid theory, implying that the latter is not electrolytic in nature. Of course, both theories are to be interpreted from the electrochemical point of view.

Auto-Colloidal Catalytic Theory

The auto-colloidal catalytic theory recently advanced by Friend, [7, 10] postulates corrosion as starting with the formation of colloidal ferrous hydroxide; this by contact with air flocculates to hydrated ferric hydroxide, which latter is alternately reduced by contact with iron oxidized by contact with air, thus continuing the corrosion and the production of rust. According to Friend, when iron comes into contact with liquid water in the presence of air or oxygen it slowly oxidizes to ferrous hydroxide; this, however, is produced in the colloidal condition—a state in which it is usual for many substances to be particularly reactive chemically. The ferrous hydroxide hydrosol is then oxidized to a higher iron hydroxide

hydrosol, and the ferric hydroxide hydrosol is produced under suitable conditions. This higher hydrosol is then alternately reduced in contact with iron and oxidized again by atmospheric oxygen, thus catalytically accelerating the oxidation of the iron, and when the sol flocculates or precipitates out it yields rust.

Hydrogen-Peroxide Theory

The presence of hydrogen peroxide in the water in which certain metals are corroded has led to the development of the hydrogen-peroxide theory. It has been demonstrated experimentally by Dunstan and his coworkers[2] that hydrogen peroxide is formed as an intermediate product during the corrosion of a number of metals including copper, lead, and zinc, but not iron. Hence, it is alleged that corrosion in many cases is owing to the formation of hydrogen peroxide and its interaction with the metal. The formation of hydrogen peroxide as a corrosion product in the oxidation of a metal by water and air is simply incidental, and this is not necessarily an accompaniment of the initiation of corrosion.

Adsorption Theory

Saklatwalla[12] has recently discussed the effect of adsorption of gases upon the rate and nature of corrosion, assuming that there is a definite relationship between the adsorption of gas by a metal and the corrosion of that metal by the same gas. The suggestion is offered that the phenomenon of adsorption, whereby a gas is condensed as a film on the surface of a metal or of any other solid body, would have the tendency of imparting to that body, surface activities, depending upon the degree of adsorption. The rate of interaction between the condensed gas of a film and the solid metal depends, among other things, upon the density of the film. If a metal has a high degree of adsorption, the condensation and consequent velocity of interaction would be high, and hence surface oxidation would take place rapidly. It is alleged that high interacting velocity, and consequent nearly instantaneous production of a protective film on the surface of the metal, is the essential factor in producing noncorrodibility. Hence, the higher the adsorption capacity, the higher should

be the noncorrodibility. The sum and substance of this theory is that certain metals are noncorrodible because they produce adsorbed surface gas films of high concentration because they in turn adsorb large amounts of gas.

Biological Theory

Claim is made by some biologists that lowly forms of life enter into the reactions which occur when iron corrodes. It is true that animal and vegetable organisms can materially enhance the corrosion of metals because of the action of their secretions, and the biological aspect of the corrosion problem should not be overlook. However, corrosion takes place readily in the absence of living matter, so that corrosion is not prevented by excluding such matter, and no organisms have so far been discovered which can feed upon metals.

Summary

No one of the theories so far advanced serves to explain the mechanism of corrosion inception and no one explains the mechanism of all the observed cases of corrosion. While the establishment of the theories have helped in the understanding of certain anomalous facts concerning corrosion, this has not given any better comprehension of the fundamental cause. The supporters of most of the theories have usually tried to make out a case for a particular theory so as to show that their theory is exclusively correct. The two foremost theories are the electrolytic and the direct oxidation hypotheses, and the position taken by some investigators (notably Bengough) is that corrosion takes place either by electrolytic or direct oxidation means. The view submitted by Bengough is that corrosion may be either chemical or electrochemical in nature and that all corrosion may be explained by one or the other of these two kinds of reactions. The acid theory is interpretable on the electrochemical basis, while the other theories are either untenable or else may be interpreted on the basis of direct oxidation.

Assuming for the moment then that all corrosion is either chemical or electrochemical in nature, the question has been asked, particularly by Bancroft[8]: Are not chemical and elec-

trochemical reactions one and the same thing? Desch and Whyte[4, 5] suggest that there is no difference between electrolytically stimulated and natural (chemical) corrosion, and this view is shared by the writers. That chemical corrosion and electrochemical corrosion are the same qualitatively, but not necessarily quantitatively, has been demonstrated experimentally by the writers.

It should be emphasized that the various theories of corrosion are really not theories which explain the cause for corrosion, but they are rather theories that serve to explain the mechanism of corrosion processes in terms of the older chemistry*.

Factors Affecting Corrosion Processes

For present purposes, corrosion may be properly regarded as chemical reaction, and many factors influence the process and determine the speed of the reaction. The corrosion of metals and alloys may take place under three different conditions: viz., (1) the corroding medium is a liquid (this may be an electrolyte or a nonelectrolyte; (2) the corroding medium is a gas or vapor; and (3) the corroding medium is alternately liquid and gas. While the cause for corrosion inception and progression is the same irrespective of the metal and the corroding medium, the rate of corrosion and the corrosion products formed would be expected to be radically different for different metals and different media. Moreover, there are a number of factors which affect the process of corrosion (chemical reaction), although the relation of these has not been thoroughly worked out.

One of the most common ways in which metals fail by corrosion is by exposure to reacting solutions (or liquids), and the factors involved in the corrosion of metals and alloys when in solution include the following:

(1) Chemical composition of the metal or alloy.
(2) Physical condition of the metal or alloy.
(3) Chemical composition and concentration of the corroding solution (liquid).

*Since the lecture was presented, the writers have applied the electronic theory of the constitution of the atom to the corrosion problem, and this permits explanation of corrosion inception in terms of modern chemistry.

(4) Velocity of the corroding medium, or the velocity of the metal in the medium.
(5) Temperature of the medium.
(6) Time period of exposure.
(7) Solution pressure of the metal which depends upon (1), (2), and (3).
(8) Electrical conditions of immersion.
(9) Effect of light.

Study of these factors should throw light on many corrosion processes, and it should be emphasized that for testing purposes, at least, it is possible to hold all of the factors constant within limits and examine the effects of variations in them.

The factors above mentioned are merely suggestive*, but indicate that in any corrosion process the effects of variable conditions must be properly accounted for.

The corrosion of any metal or alloy in any medium is an expression of the summation of the effects of all influencing factors, and for particular cases the effects may be positive, negative, zero, or negligible. The effects of the variable factors are shown in a variety of ways; viz., by the formation of salts, oxides, or hydroxides; by the deposition of metals, salts, or oxides; by the formation of coatings from the salts, which retard or accelerate corrosion, or have no effect; by the formation of pits; by passivity; by embrittlement; by selective corrosion; by disintegration; and perhaps by other effects not so common.

One of the chief difficulties in expressing the corrosion of a metal or alloy lies in the fact that a loss-in-weight determination is not necessarily indicative of the amount and character of the disintegration. Accurate loss-in-weight determinations can be made only by determining the exact composition of the adhering scale or coating as well as the weight of metal found in solution or suspension, followed by appropriate calculations. In comparing the relative corrodibility of metals, true corrosion loss-in-weight results should be expressed in terms of the molecular ratios of the metals compared. Thus, the rate of corrosion of one metal may be faster

*In the lecture, these factors were discussed at length, but owing to the confines of space, cannot be taken up here.

than that of another but the actual loss less, because of difference in the atomic weights. The rate of corrosion should properly be expressed in such terms that difference in mol weights, solution pressures, polarization, and other factors will be properly accounted for.

Summary of Recent Investigations by the Bureau of Mines

Turning now to the recent studies which have been made in the Bureau of Mines on the corrosion problem, particularly in the case of mine-water corrosion, the following gives a brief resume of the work carried out during the past three years with the results obtained. Before taking up the results of the work, it is advisable to discuss briefly the nature of acid mine water.

Nature of Acid Water From Coal Mines

As indicated previously, water from coal mines is usually decidedly acid, containing free sulphuric acid, and ferrous, ferric and aluminum sulphates, as well as sulphates of calcium, magnesium, sodium and potassium, together with silica, and usually some chlorides. On standing, dilution, aeration, or warming, insoluble iron compounds tend to precipitate from these waters, principally as hydrous ferric oxides. The occurrence of iron sulphates and free sulphuric acid is due to the action of water and air on the pyrite or marcasite associated with the coal. These sulphides are oxidized to ferrous sulphate, and sulphuric acid, and the reactions may be represented by the equations:

$$2FeS_2+7O_2+2H_2O=FeSO_4+2H_2SO_4$$
$$4FeSO_4+2H_2SO_4+O_2=2Fe_2(SO_4)_3+2H_2O$$

It is well known that the acidity and composition of different waters vary considerably at different times, and a range of composition for some waters collected at various coal mines and analyzed by the Bureau of Mines is as follows: silica, 16 to 64 p.p.m.; ferrous iron, trace to 967; ferric iron, 11 to 915; aluminum, 25 to 148; calcium, 79 to 436; magnesium, 34 to 197; sodium, 21 to 133; chlorine, trace to 25; total sulphate radical, 790 to 6370; and free sulphuric acid, trace to 3662 p.p.m. A typical analysis of filtered water (from the Edna

No. 2 mine of the Hillman Coal & Coke Co., at Wendel, Westmoreland county, Pa.) is as follows: silica, 129 p.p.m.; ferrous iron, 516; ferric iron, 1303; aluminum, 1225; calcium, 307; magnesium, 122; potassium, 332; sodium, 512; chlorine, 37; and sulphate, 11,750 p.p.m. The suspended matter (on unfiltered water) in this water dried at 105 degrees Cent. is 19 p.p.m.

It may be added that in connection with the corrosion work, study has been made by Selving and Ratliff[13] of the nature of acid water from coal mines and of methods for analysis. It was found that titration of acid mine water for free sulphuric acid with standard alkali solutions gave too high results, because of hydrolysis of sulphates of iron and aluminum. More nearly correct results were secured by reducing the ferric sulphate present to ferrous sulphate, prior to titration, and this reduction was effected by the addition of potassium-iodide solution to the mine water.

Mine Water Corrosion Tests of Iron and Steel

In 1920-1921, total immersion tests were carried out by W. A. Selvig, assistant chemist of the bureau, for committee A-5 of the American Society for Testing Materials, on the corrosion of a large number of irons and steels of varying composition in acid mine water.[9] The test samples were 2 by 6 inches in size and of 16 and 22-gage. The tests were made by immersing the specimens in flowing acid mine water at the Calumet coal mine of the H. C. Frick Coke Co., Calumet, Pa. The samples were considered to have failed after standing in the water if they had been corroded through or eaten away at the edge for a distance of ¼ inch. After failure, the samples were cleaned, weighed, and the corrosion loss calculated. Photographs of the corroded samples were made. The corrosive action of the acid mine water on all the steels and irons was severe, and the tests clearly showed that all ordinary grades of iron and steel are corroded rapidly by acid waters from coal mines and that there was no great difference in the rates of corrosion among the commercial varieties of these materials.

In these tests, the acidity due to free sulphuric acid was about 700 p.p.m. on the average, and the total acidity (that due

to free sulphuric acid plus sulphates of iron and aluminum) was about 1700 p.p.m. on the average. In all, 49 different irons and steels were tested, and comparison was made between the results obtained in mine water and those obtained on corrosion in atmospheric air. The results were quite different.

Mine Water Corrosion Tests of Forty-Five Metals and Alloys

In 1921-1922, comparative corrosion test was made of 45 metals and alloys in acid mine waters for the purpose of securing data relative to materials for use in pumping equipment. This investigation was carried out as part of a co-operative agreement between the Bureau of Mines and the Carnegie Institute of Technology. The materials tested included a variety of ferrous and nonferrous metals and alloys in the rolled and cast condition, and the waters used were from three coal mines: viz., the Montour No. 1 mine of the Pittsburgh Coal Co., at Southview, Washington county, Pa.; the Edna No. 2 mine of the Hillman Coal & Coke Co., at Wendel, Westmoreland county, Pa.; and the Calumet mine of the H. C. Frick Coke Co. at Calumet, Westmoreland county, Pa. The different materials tested were in the form of rectangular pieces 2 by 6 inches in size, the rolled materials being about 16 gage thick (0.051 inch), and the cast materials approximately ¼ inch thick. The pieces were placed in racks in test boxes especially designed for the work, so as to permit total immersion of the samples in flowing water. The construction of the test boxes and racks, which were made of wood, is shown in Fig. 1. The general arrangement of two test boxes on the surface at the Calumet mine is shown in Fig. 2. At the Montour No. 1 mine, sufficient head of water could not be obtained to cause a continuous flow of water through the boxes, and the racks holding the samples were placed in the mine sump. At the other two mines, the velocity of water flow around the samples was regulated to 1.8 inches per minute. The test covered a period of 119 days at the Montour No. 1 mine, 135 days at the Edna No. 2 mine, and 98 days at the Calumet mine. The complete results of the investigation have been reported by Selvig and one of the writers.[14]

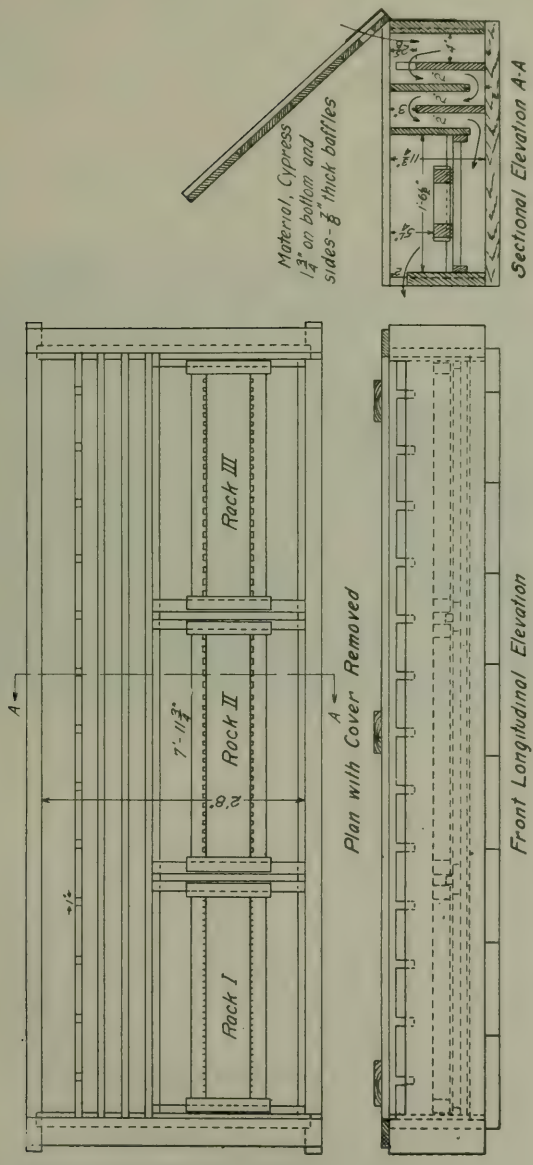


Fig. 1—Construction of Wooden Test Boxes, for Total Immersion in Acid Mine Water.

Roughly, the average acidity of the waters was as follows:

Mine	Free Acidity p.p.m.	Total Acidity p.p.m.
Montour No. 1	1430	11,360
Edna No. 2	2160	14,160
Calumet	430	2,950

Loss-in-weight data were secured for the metals and alloys after exposure to the corroding action of the mine

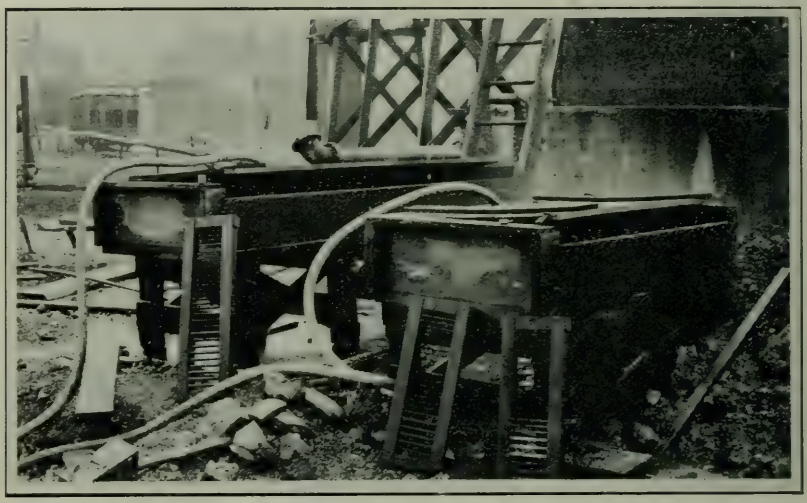


Fig. 2—Arrangement of Test Boxes for Mine Water Corrosion Tests at Calumet Mine.

waters, and the results of the work may be briefly summarized as follows:

All alloys of the brass type which were tested were corroded severely by the mine waters; the corrosion was uniform (no pitting), and the weight loss large. Bronzes were also corroded considerably, but to a less extent than the brasses, and within limits increasing tin appeared to decrease the amount of corrosion in these alloys. At the present time, bronzes are largely used for parts in pumps designed for handling acid water from coal mines. Copper-nickel alloys were corroded in about the same amount as the brasses; the loss in weight was large, and the corrosion

was uniform. Nickel silvers of various compositions (copper-nickel-zinc alloys) were badly corroded—the attack in most instances being uniform. Aluminum alloys showed a marked tendency to pronounced pitting; the loss in weight was comparatively small, but the pitting effect precludes the possibility of their use in acid mine water.

The materials which showed practically no corrosion in the mine waters included a high-chromium steel, two chromium-nickel-silicon steels, a high-silicon cast iron, and a nickel-chromium-iron alloy. All these alloys contained large amounts of chromium with the exception of the high-silicon cast iron. Commercial nickel corroded very little in the Edna No. 2 mine water but corroded considerably in the waters from the other two mines.

Taking the materials by groups, the relative corrosion losses may be taken roughly as follows, in the Edna No. 2 mine water: Brasses, 6 to 7 mg. per sq. cm. per day; bronzes, 1 to 3 mg.; cupro-nickel alloys, 5 to 7 mg.; nickel-silver alloys, 5 to 7 mg.; aluminum alloys, 2 mg.; high-silicon cast iron, 0.006 to 0.6 mg.; high-chromium steel, 0.0004 mg.; chromium-nickel-silicon alloys, 0.0002 mg.; and nickel-chromium-iron alloy, 0.002 mg. per sq. cm. per day.

A large number of the samples became covered with coatings during the course of the tests. Some of the materials had rather thick, soft, fine-grained coatings which adhered fairly tightly, but could be readily removed with a fiber brush and water. Others had loosely adhering coatings, and these could be readily removed by rinsing in water and rubbing with the hand. Some of the samples had hard, closely adhering coatings. It was shown that the coating formed may accelerate or retard corrosive action or have no appreciable effect. It should be pointed out that the physical condition of the surface of materials is a factor affecting the nature of the coating formed, and this is illustrated nicely by the photomicrographs of Figs. 3 and 4. Fig. 3 shows the coating on a copper-chromium-iron-nickel alloy, formed on an as-cast sample, while Fig. 4 shows the coating formed on the same alloy on a machined sample. The coating in the second case is much thicker and coarser than in the first case.

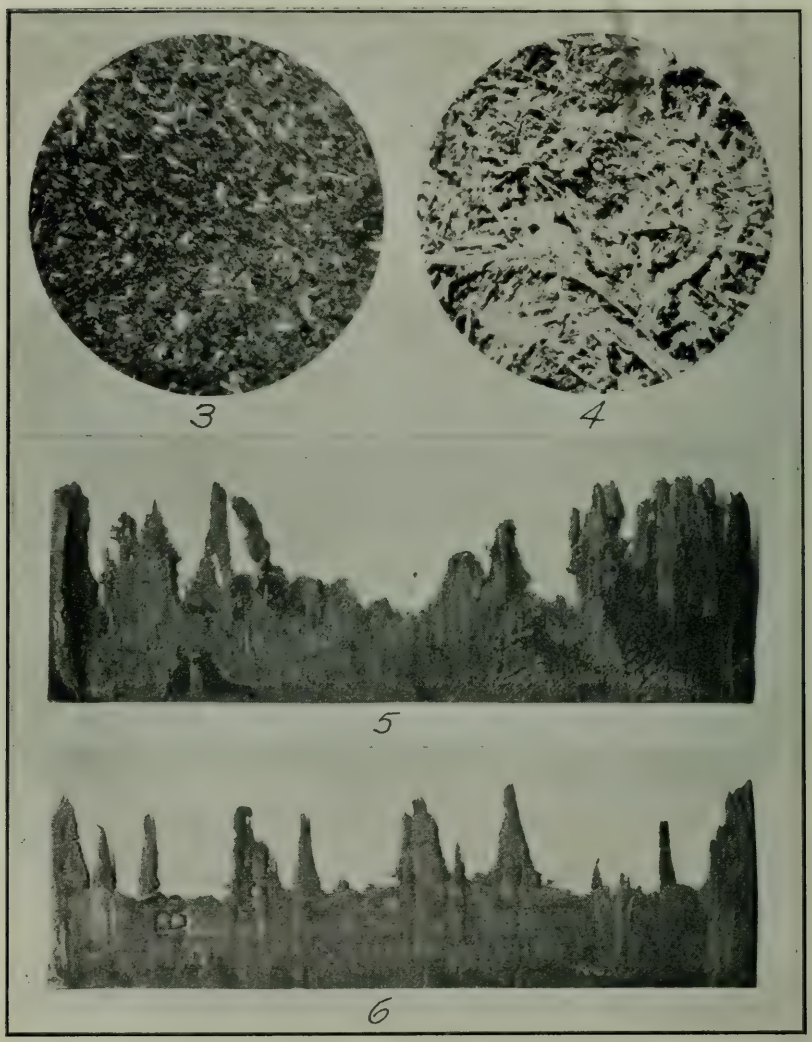


Fig. 3—Photomicrograph Showing Coating on an As-cast Sample on Exposure to Acid Mine Water. x25. Nominal Composition, 42:12:9:35, Cu-Cr-Fe-Ni (plus Si). Fig. 4—Same as Fig. 3, but on a Machined Sample, x25. Fig. 5—Rolled, High Brass. Nominal Composition, Copper 66.6%, Zinc 33.4%. Coating Easily Removable. Considerable Uniform Corrosion. Immersed 65 days—Loss in Weight, 7.38 mg. per square cm. per day. Fig. 6—Rolled, Cupro-Nickel. Nominal Composition, Copper 85%, Nickel 15%. Coating Easily Removable. Considerable Uniform Corrosion. Immersed 65 Days. Loss in Weight, 7.47 mg. per square cm. per day.

In passing, it is of interest to refer to the appearance of certain of the samples after corrosion by the acid waters,

and Figs. 5 to 11 inclusive may be noted in this connection.* Fig. 5 shows the appearance of a corroded sample of rolled, high brass, Fig. 6 a cupro-nickel alloy, Fig. 7 a cast bronze, Fig. 8 a cast copper-lead alloy, Fig. 9 a rolled aluminum-manganese alloy, Fig. 10 a rolled chromium-nickel-silicon steel, and Fig 11 a rolled high-chromium steel. The captions on the figures make the illustrations self-explanatory. All these samples were exposed to water from Edna No. 2 mine.

The investigation reviewed briefly above yielded comparative loss-in-weight data for a series of commercial metals and alloys when exposed to the action of acid mine waters, indicating that of 45 materials tested, only five were suitable from the point of view of corrosion resistance. These five materials are suitable for use in acid mine water from the point of view of resistance to corrosion, but they are not necessarily suitable when economic considerations, ease of fabrication, and physical properties are taken into account. A summary of this investigation has been given in another place by one of the writers.[16]

Microscopy of Corroded Materials

In 1922-1923, microscopic study was made of the corroded metals and alloys from the above described investigation, and the results have been published by the writers[18]. In the long-time immersion tests, a number of phenomena were observed in the behavior of the materials tested, particularly in connection with their rates of corrosion, the formation of surface coatings, and the relation of chemical composition to corrosion rates and coating formation. In the microscopic study, technique was first developed for preparing micro-sections of the corroded samples, and in all 52 samples were examined. The conclusions drawn from the work may be summarized as follows:

In brasses, grain size seems to have little effect upon the rate or nature of the corrosion. In alloy systems where two or more phases are present, there is usually, although not necessarily, one phase that is more resistant to corrosion than the other phases. This gives rise to selective corrosion. In bronzes, the delta constituent is the more resistant phase; in alpha-beta

*In the lecture, a large number of slides illustrating the appearance of corroded samples were shown, but only a few typical photographs can be given here.

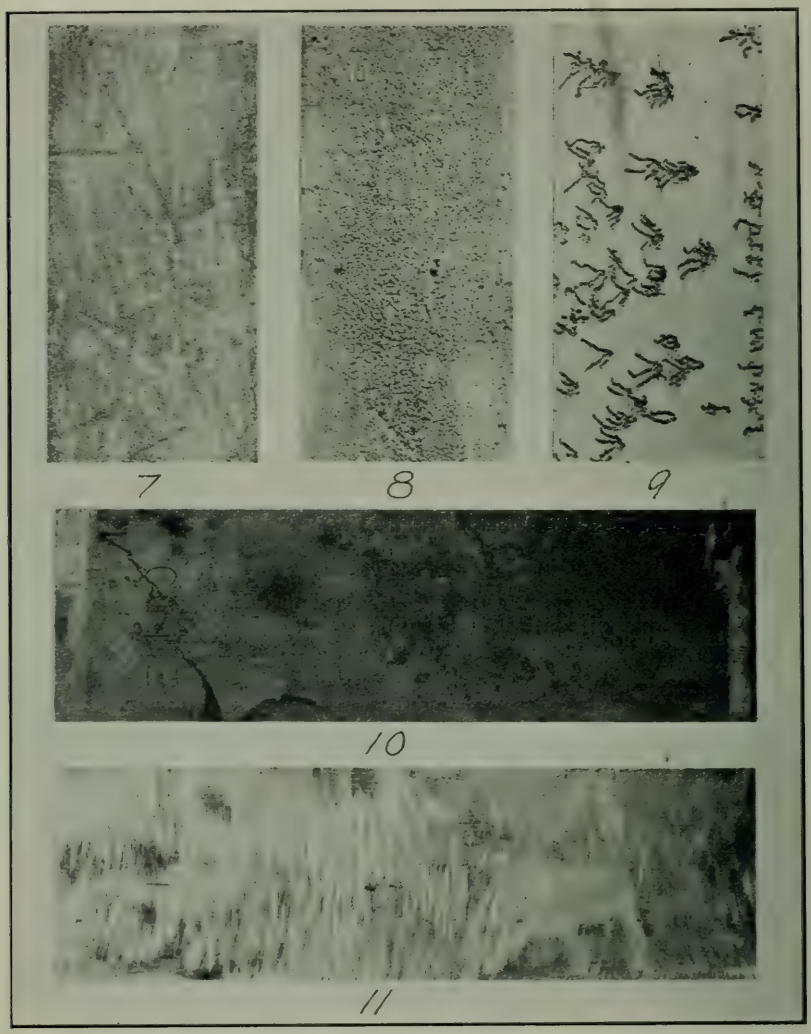


Fig. 7—Cast Bronze. Nominal Composition—Copper 90%, Tin 10%. Coating Partly Removable. Irregular Corrosion. Immersed 135 Days. Loss in Weight—1.90 mg. per square cm. per day. Fig. 8—Cast, Copper-Lead Alloy. Nominal Composition—Copper 50%, Lead 50%. Coating Easily Removable. Uniform Corrosion with some Irregular Pitting. Immersed 121 Days. Loss in Weight—3.94 mg. per square cm. per day. Fig. 9—Rolled, Aluminum-Manganese Alloy. Nominal Composition—Aluminum 98.5%, Manganese 1.5%. No Coating. Irregular Pitting. Immersed 7 Days. Loss in Weight—2.64 mg. per square cm. per day. Fig. 10—Rolled, Chromium-Nickel-Silicon Alloy. Nominal Composition—60:24:13:3, Fe:Ni:Cr:Si (with low carbon). No Coating. No Visible Corrosion. Immersed 135 Days. Loss in Weight—0.00045 mg. per square cm. per day. Fig. 11—Rolled, High Chromium Steel. Nominal Composition—Iron 70%, Chromium 30%, Carbon 0.36%. No Coating. No Visible Corrosion. Immersed 135 Days. Loss in Weight—0.00045 mg. per square cm. per day.

brass, the alpha is more resistant. The other materials examined were of such types that selective corrosion did not occur, or if it did, the constituent first corroded could not be determined. The aluminum alloys pitted so badly that selective corrosion could not be identified as such. Some alloys, which after corrosion and subsequent cleaning, appear to be free from adhering coating or precipitate, have a hard and probably quite impervious coating acting as a protection; this is particularly true of the bronzes. In general, corrosion attack does not follow grain boundaries but proceeds through the less resistant material if two or more phases be present. The more resistant material is probably removed, as such, after the less resistant material has been corroded and washed away. Microscopic examination of the corrosion resisting high-silicon iron, high-chromium steel, chromium-nickel-silicon steels, and nickel-chromium-iron alloy reveals no visible protective coating or film. The resistance of these alloys to corrosion can probably be traced to their chemical composition. It should be added that iron silicide and the double carbide of iron and chromium are very insoluble in acids.

The microstructural aspects of some of the typical corroded samples may be found of interest, and Figs. 12 to 19 inclusive may be examined in this connection.* Fig. 12 shows the corroded edge of a sample of admiralty brass; the ridge lies between shallow elongated pits. Fig. 13 shows a nodule of redeposited copper on the surface of a low brass. Fig. 14 is a macrograph of the cross section of a manganese brass, showing the very even redeposition of copper after corrosion; the dark outer edges contain about 90 per cent copper, and the light center area is the uncorroded brass. Fig. 15 shows the grain boundaries, retained from the original structure, in the redeposited copper of Fig. 14. In Fig. 16 is shown the corroded edge of a leaded bronze, with the delta constituent standing up at the edge. Fig. 17 is a macrograph of substantially pure aluminum, showing the deep pits formed. Fig. 18 shows the pitting in a copper-lead alloy, resulting from the selective corrosion of the copper. Fig. 19 shows cracking in a high lead alloy, which actually gained in weight on exposure to the

*In the lecture, a large number of slides showing the microstructure of corroded samples were presented, but only a few typical micrographs can be reproduced here.

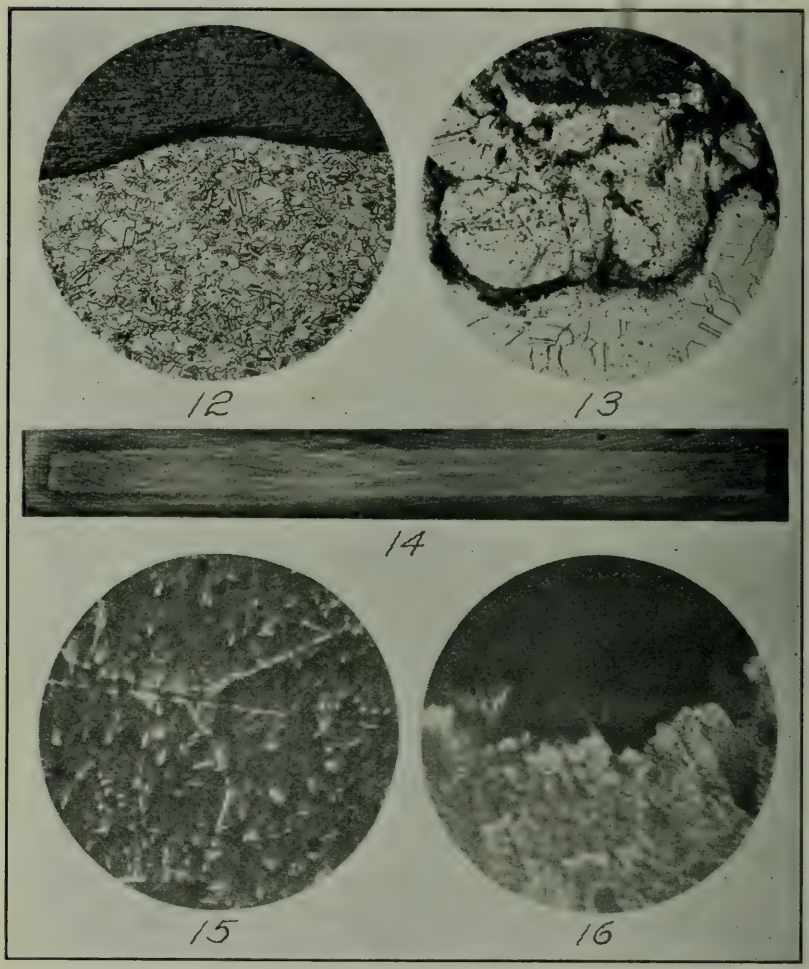


Fig. 12—Edge of Admiralty Brass. Nominal Composition, Copper 70%, Zinc 29%, Tin 1%. Grain Size, 0.035 mm. Immersed 35 Days. Etched in Ammonia and Hydrogen Peroxide. x100. Fig. 13—Low Brass. Nominal Composition—Copper 80%, Zinc 20%. Immersed 119 Days. Photomicrograph Shows Nodule of Re-deposited Copper on Surface. Etched with Ammonia and Hydrogen Peroxide. x100. Fig. 14—Manganese Brass. Nominal Composition—Copper 68%, Zinc 28%, Iron 2%, Manganese 2%, Cross-section of Test Piece Showing Redeposition of Copper. Immersed 72 Days. Oblique Illumination x2. Fig. 15—Showing Microstructure of the Outer Edge of Fig. 14. Etched with Ammonia, Hydrogen Peroxide and Acidulated Ferric Chloride. x300. Fig. 16—Cast, Lead Bronze. Nominal Composition—Copper 75%, Tin 10%, Lead 15%. Immersed 135 Days. Etched in Acidulated Ferric Chloride. x300.

mine water. The samples represented by these figures were all exposed to the Edna No. 2 mine water with the exception of Fig. 13, where the sample was exposed to the Montour No. 1 mine water. The captions on these several figures make the

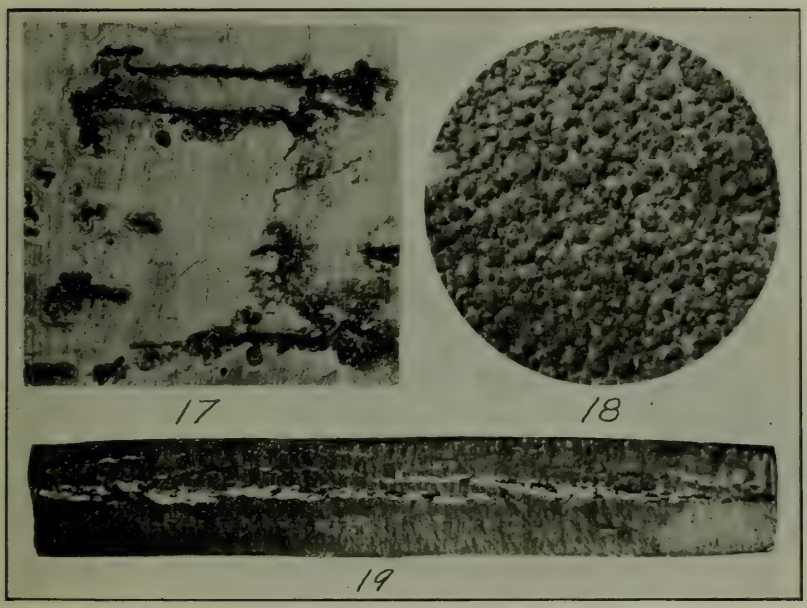


Fig. 17—Substantially Pure Aluminum. Immersed for 21 Days. Unetched. x2. Fig. 18—Cast, Copper-Lead Alloy. Nominal Composition—Copper, 50%, Lead 50%. Immersed 121 Days. Unetched, Oblique Illumination. x5. Fig. 19—Cast, High Lead Alloy. Lead 96% plus Alkaline-Earth Metals. Immersed 72 Days. Unetched, Oblique Illumination. Cross-section. x2.

illustrations self-explanatory. Since the alloys which were very resistant to corrosion were not visibly attacked, photomicrographs of these need not be included.

This investigation demonstrated the desirability of microscopic examination in the study of corrosion, and the writers feel that considerable light can be thrown on corrosion processes by microscopic study of corroded samples.

Fundamentals of Corrosion

In 1922-1923, study was made by the writers and J. R. Adams of the fundamentals of corrosion and the factors affecting corrosion processes. In this connection, the various

theories of corrosion were examined and it was shown that these do not serve to explain corrosion inception although they can be applied to explain different corrosion processes in terms of the older chemistry*.

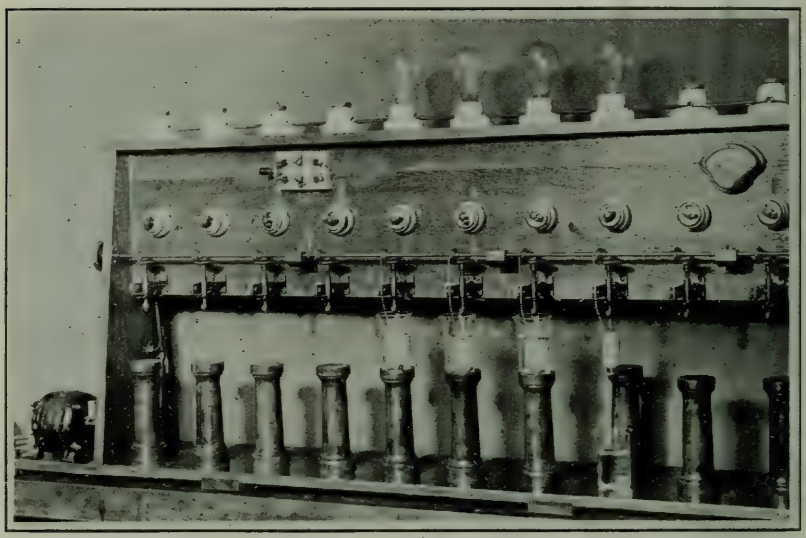


Fig. 20—Set-Up of Electrolytic Cabinet for Accelerated Electrolytic Tests.

Accelerated Corrosion Testing

In 1922-1923, investigation was made by the writers and J. R. Adams of the possibility of developing an accelerated test for corrosion. The attempt was first made to develop an accelerated chemical test, so-called, in which test samples were corroded in a liquid medium and acceleration given by introducing oxygen or air into the medium. It was found that the acceleration by this method over the ordinary long-time immersion test was very slight, and this method was abandoned. The attempt was next made to develop an accelerated electrolytic test, and this was entirely successful. A number of experiments were made on the electrolytic corrosion of bronzes in order to repeat the work reported by previous investigators, and duplicate results were readily obtainable. In

*Since this lecture was given, the writers have applied the electronic theory of the constitution of the atom to the corrosion problem, and this permits explanation of corrosion inception in terms of modern chemistry.

carrying out this work, cylindrical samples of copper—tin alloys were made anode in several solutions including sodium chloride, sodium sulphate, sodium nitrate, and ammonium oxalate plus oxalic acid. The test pieces were rotated, and the current density was 0.179 amperes per square decimeter, of exposed surface area. Runs were also made where the effects of several factors, including variation in current density, time of exposure, and shape of test piece, were examined.

Finding that the results of other investigators could be readily duplicated, accelerated electrolytic corrosion tests were made on 42 of the metals and alloys corroded in long-time immersion test in the previous investigation by W. A. Selvig and one of the writers[14], and the results of both tests were correlated. Mine waters from the Montour No. 1, the Edna No. 2, and the Calumet mines were used as the electrolytes. Fig. 20 shows the apparatus employed for the tests; this is simply an ordinary electrolytic apparatus, with rotating anode spindle connections, as used for the analysis of metals and alloys but built especially for corrosion testing. It was shown as a result of these tests that the corrosion of metals and alloys can be greatly accelerated by the electrolytic method*.

Summary

This paper has discussed the corrosion problem briefly and in a general way, especially as applied to corrosion of metals and alloys in acid mine waters. The following is a brief summary:

1. The U. S. Bureau of Mines has been carrying on an investigation of corrosion for three years in co-operation with the Carnegie Institute of Technology, dealing particularly with the corrosion of metals and alloys in acid mine waters.

2. Considerable trouble is experienced by mine operators in the western Pennsylvania coal region because of the corrosion of equipment, notably pumps, by acid mine waters.

3. The several theories of corrosion are discussed briefly, and it is pointed out that these do not explain the fundamental cause for corrosion.

4. Total immersion tests have been made on a large

*Since the lecture was presented, this work has been developed and elaborated, and the complete results will be published later.

number of irons and steels for corrosion in acid mine water, and it has been shown that the corrosion is much different from that in air.

5. Long-time immersion tests have been made on 45 metals and alloys in three acid mine waters for corrosion, and the comparative corrodibility determined. The data obtained are of value in selecting alloys for mine pumps.

6. Study has been made of the microstructural aspects of these 45 metals and alloys after corrosion.

7. Study has been made of the fundamentals of corrosion.

8. An accelerated electrolytic test has been developed for determining the corrodibility of materials in electrolytes.

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Bibliography concluded on page 647

HIGH-POWER PHOTOMICROGRAPHY OF METALLURGICAL SPECIMENS

By Francis F. Lucas

Abstract

The subject of high-power photomicrography of opaque metallurgical specimens is discussed in this paper. The author points out that it is more or less an accepted idea that photomicrographs in excess of 1500 *diameters magnification are of little or no value. Exception is taken to this point of view and the author shows that remarkable definition may be attained at high magnifications. Representative photomicrographs, principally of academic interest, are reproduced to show the attainment of definition, resolution, and penetration at high powers.*

The author discusses briefly and somewhat generally the possibility of high-power metallography, the best type of equipment to use and the need for great care in the preparation of the specimen.

The halftone reproductions inevitably show less detail and brilliancy than the original photomicrographs.

PHOTOMICROGRAPHY of metallurgical specimens is generally confined to magnifications ranging from a few diameters to about 1500. Very few pictures of metal structures have been published at magnifications exceeding 1000 diameters, and apparently many people believe that magnifications in excess of 1500 diameters are of little or no value.

Usually no one photomicrograph will serve for all purposes. Low-power work may be likened to an observer at a lookout station on a mountain top. He sees the country for miles around and by his elevated viewpoint he obtains perspective. Let him observe the ground upon which he stands and he loses the broad general view, but is able to grasp small details wholly unseen in the distant view—virtually a case of high-power work.

A paper by Francis F. Lucas, the photomicrography of which was performed in the research laboratories of the American Telephone & Telegraph Co. and the Western Electric Co., Inc., New York City.

That most photomicrographs are taken at low or medium powers is due, no doubt, to the fact that the equipments ordinarily purchased are not suited to high-power work and consequently development in proficiency has been confined to the field of low or medium power work. To get satisfactory results at high-powers and to get these results consistently, precision equipment is indispensable. The apparatus must be substantially constructed and made for precision work. A compromise outfit which may be adapted to the requirements of both transparent and opaque specimens is only courting trouble because rigidity must necessarily be sacrificed to some extent in order to provide means for adjusting the stand to suit the different classes of work.

At the present time the limitations of high-power metallography do not appear to be with the precision equipment now available but rather with the technique of preparing metallurgical specimens for examination at high powers. It is quite desirable to know the limitations of the apparatus, but it is of considerably more importance to know how best to use the finest equipment to its utmost, because increase in knowledge and better tools go hand in hand. So far as metallurgical work is concerned, it seems to be true that the quality of the best objectives surpasses by far the ability to use them to best advantage.

The Arc as a Light Source

Much has been written on the subject of illuminants for photomicrography, and many statements may be found derogatory to arc lamps, but as a real source of light, a smoothly operating automatic arc lamp equipped with suitable carbons is capable of yielding results of the highest order. Most writers complain of a sputtering arc or irregular feeding of the carbons, but these troubles are readily overcome. Direct current is necessary for successful operation and the carbons should be of small diameters so that the ultimate result will approach closely a point source of illumination. Most automatic arc lamps of this sort have been designed for a certain current, usually about five amperes, and unless the current rating is closely adhered to in practice, the operation is apt to be irregular. Probably the most important part of the illuminant from an operating standpoint is the grade of carbons used. What is needed for high-power work is a point source of light (or approximately so) of great brilliancy, capable

PLATE I
Magnification 1690 X

SUBJECT:	Crystal Grain Orientation in Wrought Iron.
ETCH:	5 per cent Solution of Picric Acid in Alcohol and re-etched with ammonium persulphate, 2 grams to 10 cubic centimeters of water.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-18, 20 X.
FILTER:	Wratten "B" 4600 to 5100 A.U.
PLATE:	Wratten "M."
EXPOSURE:	3 minutes.

of being smoothly and uniformly controlled so that the luminous end of the positive carbon will not fluctuate backward and forward within wide limits. As a matter of convenience the carbon adjustment for the initial setting should be such that replacement of the carbons will not consume much time.

Optical Parts — *The Objective*

A great deal may be said about the optical parts, but the objective is the most important part of the whole outfit. No one objective will suffice, and therefore, it is highly desirable to have a whole battery available so that the objective may be selected to suit the requirements of the work. Objectives are divided into four general classes: first, achromatic; second, semiapochromatic;

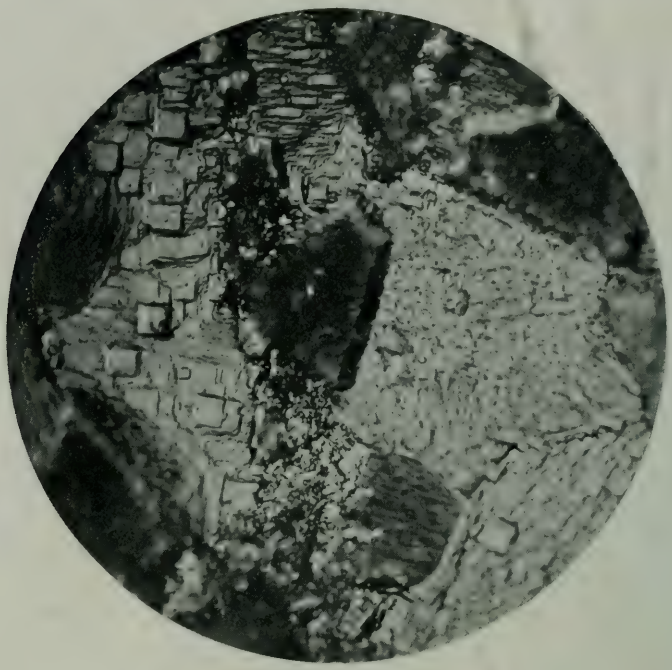

PLATE II
Magnification 1690 X

SUBJECT:	The Cubic Crystallization of Iron.
ETCH:	5 per cent Solution of Picric Acid in Alcohol and re-etched with ammonium persulphate, 2 grams to 10 cubic centimeters water.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-12, 15 X.
FILTER:	Wratten "B" 4600 to 6000 A.U.
PLATE:	Wratten "M."
EXPOSURE:	1½ minutes.

third, apochromatic, and fourth, those for use with ultra-violet light. Of the first three the difference is primarily one of correction for chromatic and spherical aberrations. The apochromats being the most highly corrected are the ones best suited to high-power work.

It is the objective which produces the image; the eyepiece and bellows extension which add magnification. If the objective fails to resolve detail, the final result will be wanting. Obviously, if we are interested in high-power work we are interested in resolving very fine detail; otherwise there would be no object in attempting high magnifications. The resolving power of an objective depends, primarily, upon two things: the numerical aperture of

the objective and the wave-length of the light used. The brightness of the image also varies directly as the square of the numerical aperture. As the numerical aperture increases the flatness of the field and the depth of penetration decrease but usually when high resolution is desired flatness of the field and penetration are not of great concern. For high-power work a Zeiss 2 millimeter apochromatic objective of 1.4 numerical aperture leaves very little to be desired and when used under favorable conditions, these objectives are capable of yielding remarkable depth of penetration at high-powers.

By controlling the color of the light used in photomicrography it is possible to obtain contrast and to improve definition,

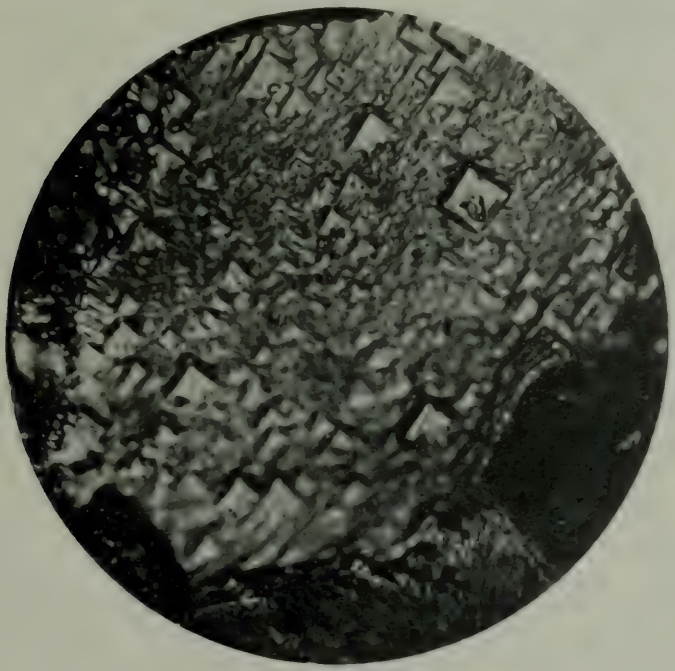

PLATE III
Magnification 2450

SUBJECT:	The Cubic Crystallization of Iron.
ETCH:	5 per cent solution Picric Acid in Alcohol and re-etched with ammonium persulphate, 2 grams to 10 cubic centimeters water.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-12, 15 X.
FILTER:	Wratten "B" 4600 to 6000 A.U.
PLATE:	Wratten "M."
EXPOSURE:	1 minute.

PLATE IV
Magnification 1050 X

SUBJECT: Nickel-iron Alloy.
ETCH: Twenty minutes in a solution consisting of 10 cubic centimeters Nitric Acid, 7.5 cubic centimeters Glacial Acetic Acid and 7.5 cubic centimeters Acetone.
OBJECTIVE: Bausch & Lomb 4 millimeter Achromat.
N. A. 0.65.
OCULAR: Zeiss 20 X.
FILTER: Wratten "E" 5600 A. U. to Red End to Secure Contrast.
PLATE: Wratten "M."
EXPOSURE: 3½ seconds.

This photomicrograph illustrates a nickel-iron alloy at what is usually considered high magnification. Very small triangular shaped pits are shown developed but the magnification is not sufficient to reveal the structure clearly. The following two plates show this crystal structure well developed.

but of greater importance in high-power work is the fact that the resolving power may be increased by decreasing the wave-length of the light used. The relation is expressed as follows:

$$\text{Number of lines per inch resolved} = \frac{2\ \text{N. A.}}{\text{Wave-Length}}$$

Assuming that a Wratten "F" ray-filter is used whose transmission band is from 6100 angstrom units to the red end of the spectrum then an objective of 1.4 numerical aperture should re-

solve about 109,000 lines per inch. If a "C" ray-filter is used whose spectral transmission is from 4000 angstrom units to 5100 angstrom units the same objective should resolve about 158,000 lines per inch. That is, by using the shorter wave-length light it is possible to effect a theoretical improvement of about 45 per cent in the resolution. In practice there is some departure from these theoretical values because of the complications entering into the problem.

If ultraviolet light were used, the resolution would be

PLATE V
Magnification 2300 X

SUBJECT:	A Nickel-iron Alloy.
ETCH:	Thirty minutes in a solution consisting of 10 cubic centimeters Nitric Acid, 7.5 cubic centimeters Glacial Acetic Acid and 7.5 cubic centimeters Acetone.
OBJECTIVE:	Spencer 1.8 millimeter Achromat.
N. A.	1.25.
OCULAR:	Zeiss 20 X.
FILTER:	Wratten "E" 5600 A. U. to Red End to Secure Contrast.
PLATE:	Wratten "M."
EXPOSURE:	15 seconds.

A development of crystal structure from the specimen shown in Plate IV, the object of which was to show the crystal form. A further development at higher magnification is shown in Plate VI.

greater than when using light whose wave-length lies within the visible spectrum. Since glass is opaque to ultraviolet light, lenses of another material must be used. Monochromatic quartz objectives are available for this purpose.

Preparation of Specimens an Important Factor

When considering the problem of high-power work with metallurgical specimens it is necessary to keep in mind that the surface to be examined must be prepared with the greatest of care, as it is probable that many failures attributed to the optical parts are in reality due to the faulty preparation of the specimen. This has been found to be true in the Bell System laboratories where actual experimental investigations have been carried out and a rather elaborate technique of polishing developed to meet the requirements. It is conceivable that a polish suitable for low or medium-power work would appear rough at 6000 diameters. It has been found that the more perfect the polish the better will be the definition. Further experimental investigations developed the fact that contrary to the usually expressed statement, a light etch does not necessarily give the best results at high powers. If a specimen is to photograph well and yield sharp definition, a contrasting etch is absolutely essential. To obtain the desired result, the etching reagent must be adjusted to the conditions and applied gradually, several applications being preferable to a single one. Examination of the specimen after the first application should show the structure delicately revealed but lacking in contrast. Perhaps the result may best be described by saying that it is "flat," a term well understood in photography. Such structures do not photograph well, but if the pattern is further developed by repeated applications, a state will be reached when the pattern stands out in great contrast and is sharply defined. When this stage is reached the specimen is ready to be photographed and the results are striking, both visually and photographically.

It is recognized that metallurgical specimens tarnish readily and even for low-power work are found unsatisfactory several days after etching and often in less time. This tarnishing effect appears to be cumulative. The writer has found that for high-power work the contrast above described becomes seriously impaired for iron and steel specimens after about one and one-half hours

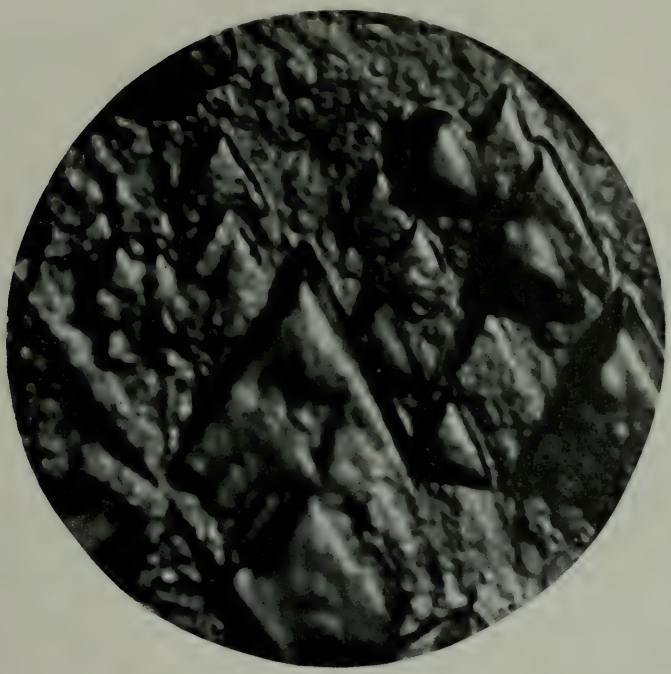

PLATE VI
Magnification 4300 X

SUBJECT:	A Nickel-iron Alloy.
ETCH:	Forty minutes in a solution consisting of 10 cubic centimeters Nitric Acid, 7.5 cubic centimeters Glacial Acetic Acid and 2.5 cubic centimeters water.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-18, 20 X.
FILTER:	Wratten "E" 5600 A. U. to Red End to Secure Contrast.
PLATE:	Wratten "M."
EXPOSURE:	20 seconds.

This is a further development of the crystal structure illustrated in Plate V.

and its effect becomes quite noticeable at 6000 diameters after about thirty minutes. As the contrast decreases due to the tarnishing effect the specimen becomes "flat" in appearance and a good focus is difficult to obtain. For this reason it has been found necessary to photograph the specimen immediately after etching.

Effect of Vibration Overestimated

Vibration has been blamed for many indistinct photomicrographs, and elaborate precautions are often recommended to offset the effect. This trouble appears to be greatly exaggerated. If the

PLATE VII
Magnification 3500 X

SUBJECT:	Normal Structure 0.10 per cent Carbon Steel.
ETCH:	5 per cent Solution Picric Acid in Alcohol. A progressive etch to develop contrast.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Projection Eye-piece P-4.
FILTER:	Wratten "H" 4200 to 5400 A.U.
PLATE:	Wratten Panchromatic.
EXPOSURE:	40 seconds.

PLATE VIII

Magnification 3000 X

SUBJECT: Normal Structure 0.10 per cent Carbon Steel.
ETCH: 5 per cent Solution of Picric Acid in Alcohol.
OBJECTIVE: Zeiss 2 millimeter Apochromat.
N. A. 1.4.
OCULAR: Projection P-4.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten Panchromatic.
EXPOSURE: 22 seconds.

Prolonged etching dissolves the ferrite but does not affect the cementite. The latter stands out in relief and under high powers this treatment shows very clearly the form of the cementite plates.

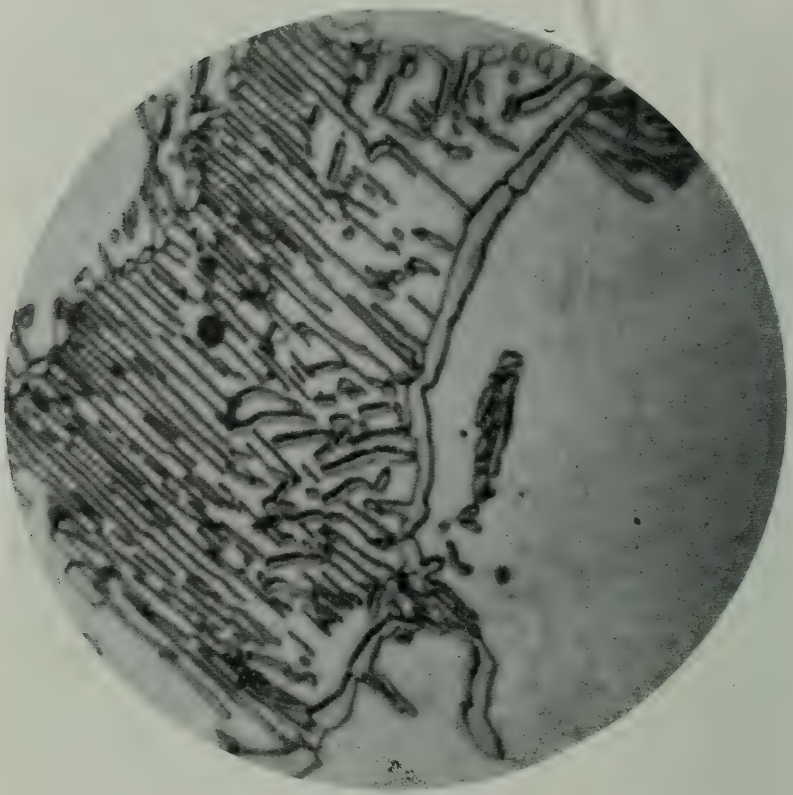

PLATE IX

Magnification 3500 X

SUBJECT: Normal Structure 0.20 per cent Carbon Steel (Pearlite Area).
ETCH: 5 per cent Solution Picric Acid in Alcohol.
OBJECTIVE: Zeiss 2 millimeter Apochromat.
N. A. 1.4.
OCULAR: Projection P-4.
FILTER: Wratten "C" 4000-5100 A.U.
PLATE: Wratten Panchromatic.
EXPOSURE: 25 seconds.

See Plate X for same field at 9000 X.

specimen is properly prepared (polished) and etched so that it can be focussed sharply and if it is photographed immediately, experience in our laboratory seems to indicate that ordinary vibrations such as those encountered in the usual steel frame building are of small importance and can be overcome readily by sponge rubber pads underneath the supporting legs of the stands. This means that people walking nearby; distant machine tools in operation or other dis-

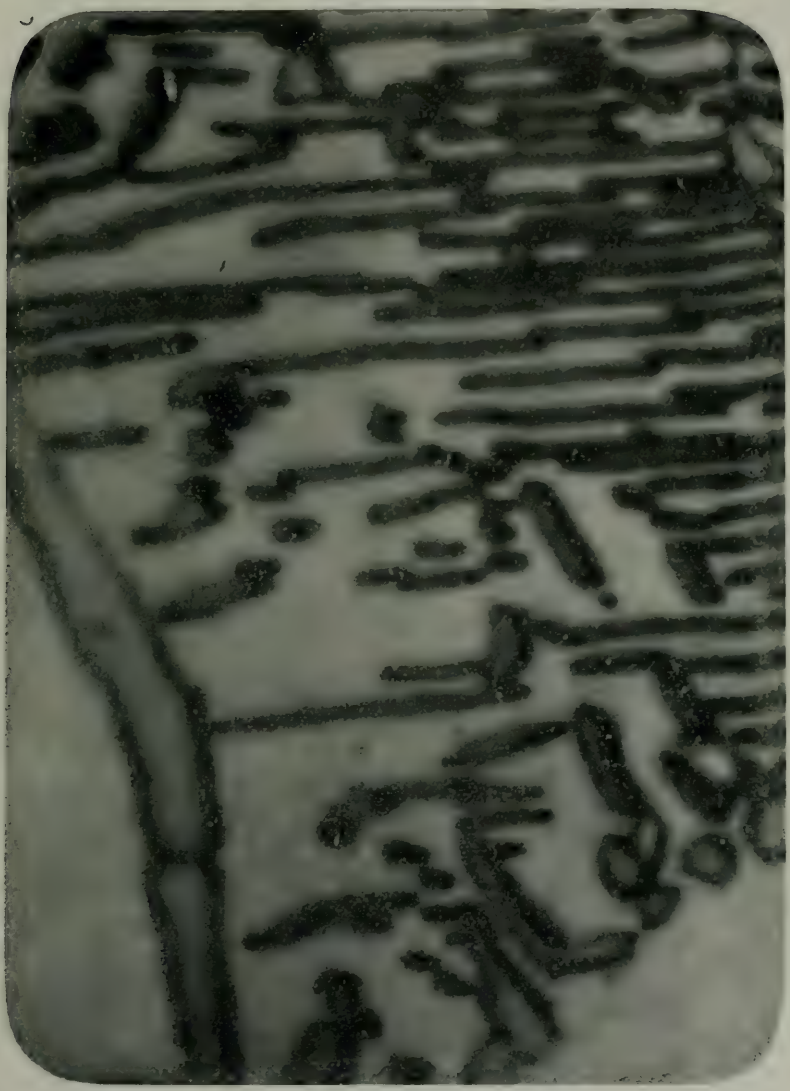

PLATE X

Magnification 9000 X

SUBJECT:	Normal Structure 0.20 per cent Carbon Steel (Pearlite Area).
ETCH:	5 per cent Solution of Picric Acid in Alcohol.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-12. 15 X.
FILTER:	Wratten "B" 4000 to 5100 A.U.
PLATE:	Wratten Panchromatic.
EXPOSURE:	45 seconds.

See Plate IX for same field at 3500 X. This specimen yielded a very brilliant image, consequently a rather short exposure could be made. Even at this extreme magnification it can be seen that the specimen is very highly polished. However, the technique of etching for high-powers, and the need for photographing at once was not fully appreciated or understood when Plates IX and X were taken. In consequence, it is probable that better results might be obtained if these pictures were to be retaken with the knowledge acquired by later developments in the art.

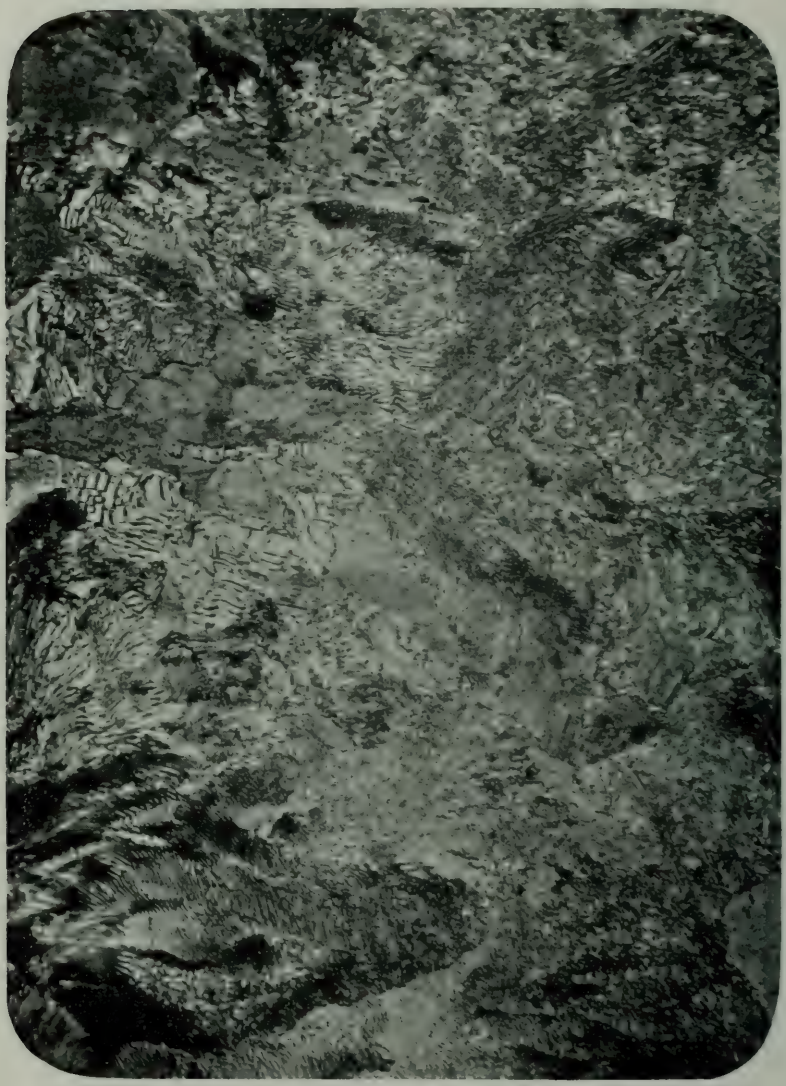

PLATE XI
Magnification 520 X

SUBJECT: Normal Structure of Eutectoid Steel.
ETCH: 10 per cent Solution Nitric Acid in Alcohol.
OBJECTIVE: Zeiss 8 millimeter Apochromat.
N. A. 0.65.
OCULAR: P-4 Projection Eye-piece.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten Panchromatic.
EXPOSURE: 8 seconds.

The object of this photomicrograph is to illustrate at medium-power the same specimen which is shown at higher powers in Plate XII.

PLATE XII
Magnification 6000 X

SUBJECT: Normal Structure Eutectoid Steel.
ETCH: 5 per cent Solution Nitric Acid in Alcohol. A progressive etch to develop contrast.
OBJECTIVE: Zeiss 2 millimeter Apochromat.
N. A. 1.4.
OCULAR: Zeiss Compensating K-8, 10 X.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Seeds "L" Ortho.
EXPOSURE: 75 seconds.

The same specimen as illustrated at lower magnification in Plate XI. This photomicrograph offers some interesting possibilities in the way of measuring the dimensions of very small details. For instance, the ferrite plates for this and several other fields taken at the same time average about 1-20,000 inch in thickness and the cementite plates about 1-30,000 inch. The grain boundaries in this plate are defined clearly and measure 1-250,000 inch in thickness.

PLATE XIII
Magnification 520 X

SUBJECT: Normal Structure of 1.5 per cent Carbon Steel.
ETCH: 10 per cent Solution of Nitric Acid in Alcohol.
OBJECTIVE: Zeiss 8 millimeter Apochromat.
N. A. 0.65.
OCULAR: Projection Eye-piece P-4.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten Panchromatic.
EXPOSURE: 8 seconds.

The object of this photomicrograph is to illustrate the structure at medium-power. See Plate XIV for the same specimen at 6000 X.

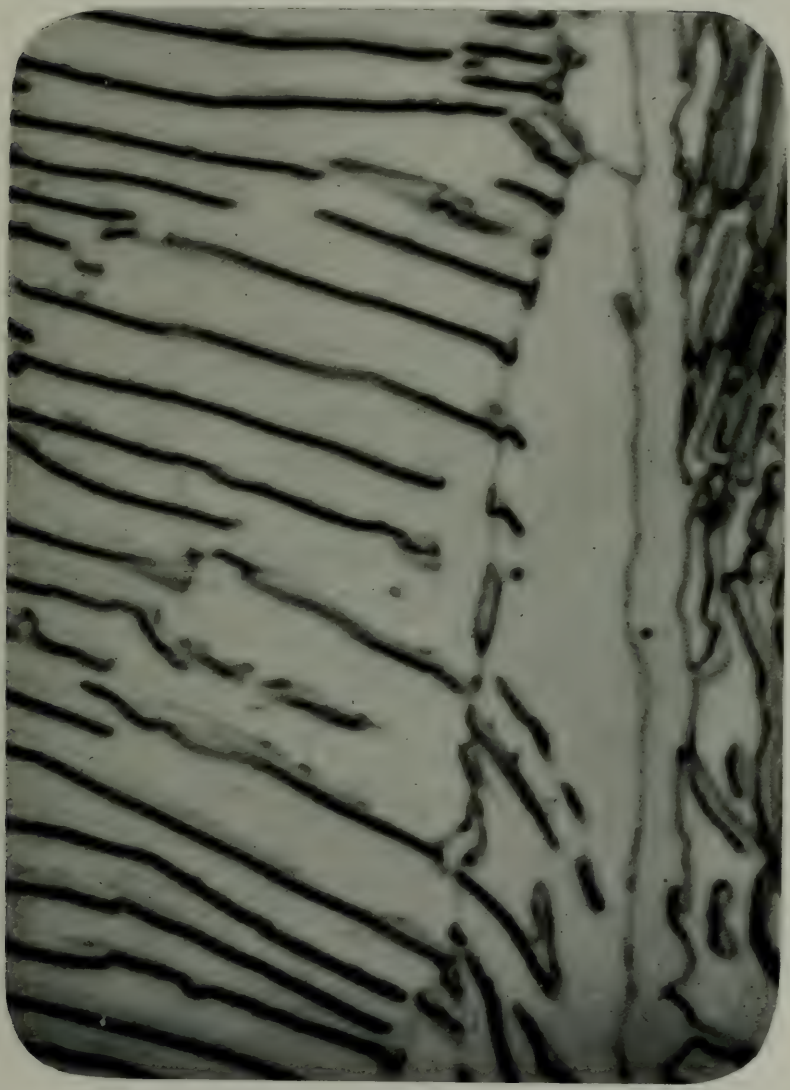

PLATE XIV

Magnification 6000 X

SUBJECT:	Normal Structure 1.5 per cent Carbon Steel.
ETCH:	Two dips in 3 per cent solution of Picric Acid in Alcohol and one dip in a 1 per cent solution of Nitric Acid in Alcohol.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-8, 10 X.
FILTER:	Wratten "H" 4200 to 5400 A.U.
PLATE:	Wratten Panchromatic.
EXPOSURE:	1 minute, 52 seconds.

The same specimen as illustrated in Plate XIII at 520 X. High magnification brings out the grain boundary and the free cementite at the grain boundary. The depth of the etching in the ferrite plates is evident.

PLATE XV
Magnification 24 X

SUBJECT: Cast Cobalt of High Purity.
ETCH: Aqua Regia and re-etched with Ferric Chloride and Hydrochloric Acid.
OBJECTIVE: Zeiss 50 millimeter micro-planar.
OCULAR: None.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten "M."
EXPOSURE: 25 seconds.
ILLUMINATION: Oblique Light.

Before etching, this specimen showed a perfectly polished surface at 400 diameters. It is of interest to note the angular relationship of the lines developed by etching, and to compare these with the orientation and crystal formation developed at higher magnifications in Plates XVI to XIX, inclusive.

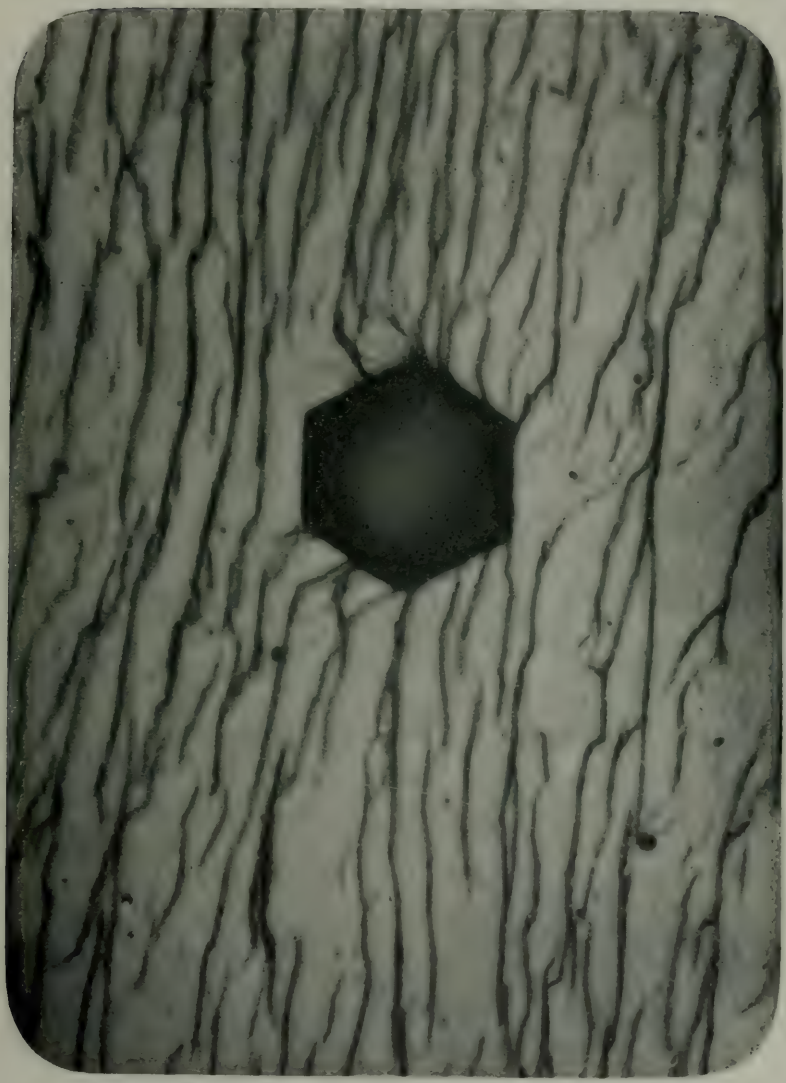

PLATE XVI

Magnification 2950 X

SUBJECT: Cast Cobalt of High Purity.
ETCH: Aqua Regia and re-etched with Ferric Chloride and Hydrochloric Acid.
OBJECTIVE: Zeiss 2 millimeter Apochromat.
N. A. 1.4.
OCULAR: Zeiss Compensating K-12, 15 X.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten "M."
EXPOSURE: 25 seconds.

A portion of one of the crystal grains shown in Plate XV.

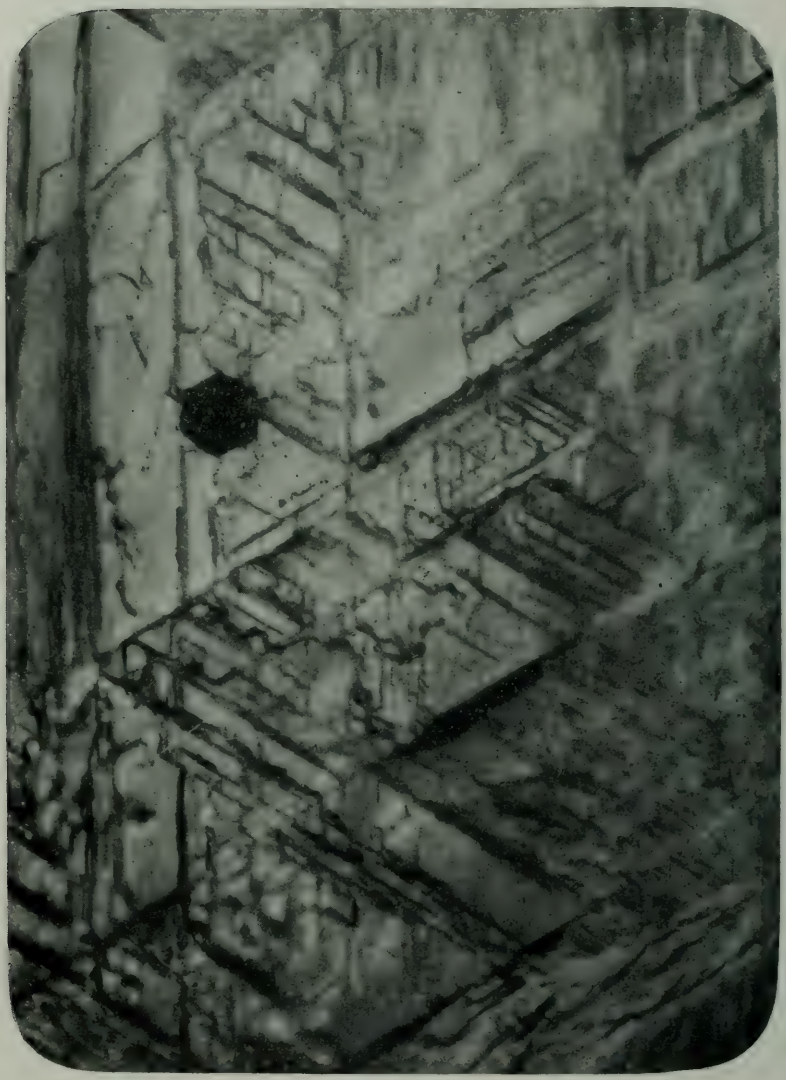

PLATE XVII
Magnification 1600 X

SUBJECT: Cast Cobalt of High Purity.
ETCH: Aqua Regia and re-etched with Ferric Chloride and Hydrochloric Acid.
OBJECTIVE: Zeiss 3 millimeter Apochromat.
N. A. 1.4.
OCULAR: Zeiss Compensating K-8, 10 X.
FILTER: Wratten "D" and "H." Dominant Wave Length 4500 A.U.
PLATE: Wratten "M."
EXPOSURE: One and one-half minutes.

This photograph shows a further development of the crystalline structure of pure Cobalt. The pattern resolves itself into hexagons, equilateral triangles and rhomboids, which appear to be indicative of crystallization in the cubic and the hexagonal systems.

PLATE XVIII
Magnification 2950 X

SUBJECT: Cast Cobalt of High Purity.
ETCH: Aqua Regia and re-etched with Ferric Chloride and Hydrochloric Acid.
OBJECTIVE: Zeiss 2 millimeter Apochromat.
N. A. 1.4.
OCULAR: Zeiss Compensating K-12, 15 X.
FILTER: Wratten "C" 4000 to 5100 A.U.
PLATE: Wratten "M."
EXPOSURE: 25 seconds.

A portion of one of the crystal grains shown in Plate XV. The appearance and angular arrangement of the etching pit would seem to indicate that the surface of the specimen corresponds very closely to a cleavage plane.

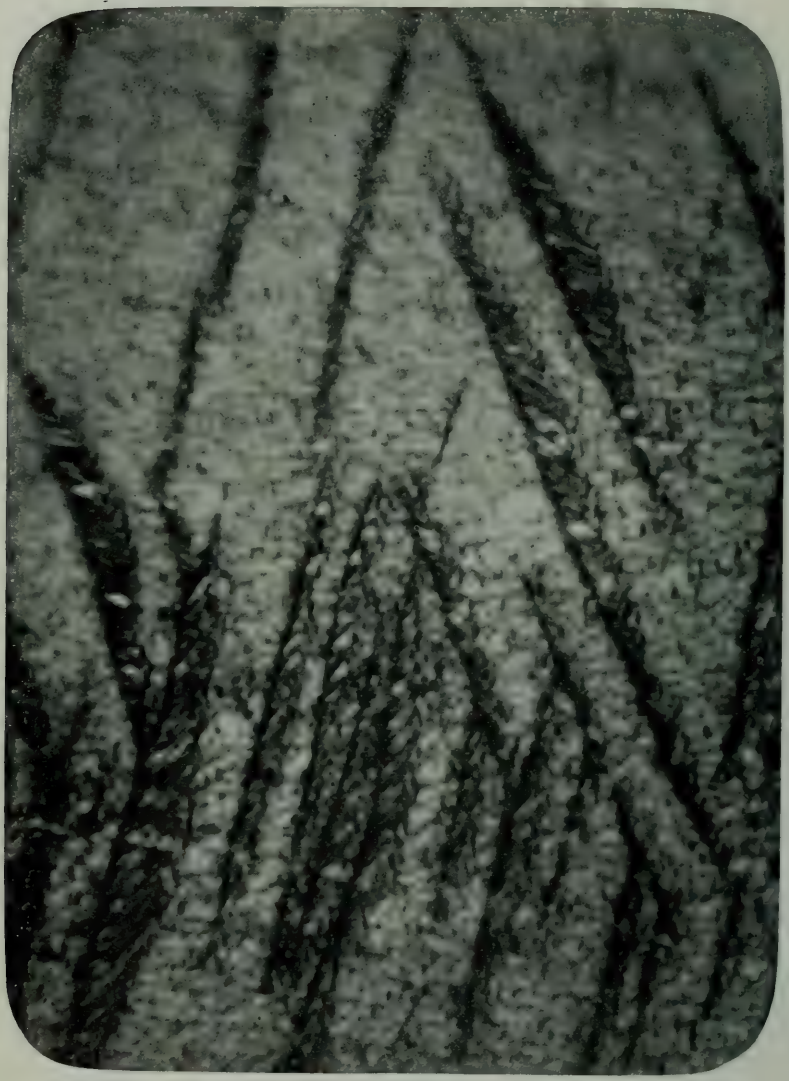

PLATE XIX

Magnification 2950 X

SUBJECT:	Cast Cobalt of High Purity.
ETCH:	Aqua Regia and re-etched with Ferric Chloride and Hydrochloric Acid.
OBJECTIVE:	Zeiss 2 millimeter Apochromat.
N. A.	1.4.
OCULAR:	Zeiss Compensating K-12, 15 X.
FILTER:	Wratten "C" 4000 to 5100 A.U.
PLATE:	Wratten "M."
EXPOSURE:	25 seconds.

This photograph seems to indicate that the Widmanstatten structure has formed and if several of the preceding plates are examined closely, the same structure will be evident.

turbances of slight or moderate intensity can usually be ironed out by a really simple expedient. Because a photomicrograph is "fuzzy" does not necessarily imply that vibration made it so. Polish, etch, tarnish and focus—one or all—may have been responsible.

Exact Focussing Essential

High-power work calls for exact focussing. This is somewhat difficult with the present apparatus because the rigging attached to the fine adjustment for distant control is neither sufficiently slow moving nor exact enough in its adjustment. The objection is not a serious one as refinements in the mechanism are possible. In practice the image first is roughly focussed on a ground glass screen after which the operation is completed on a clear glass screen with the aid of a focussing magnifier. If a dark filter such as a "C" filter or the "D" and the "H" filters together are inserted in the light beam the final focussing can be made with more exactness.

The Value of High-Power Photomicrographs

The question has often been asked, "What do high-power photomicrographs show that cannot be shown by lower magnifications?" The usual answer seems to be that high-power pictures have not added to our store of knowledge although they have constituted an interesting if somewhat "fuzzy" exhibit. According to the writer's way of thinking this is not the real answer.

The fact that secondary structure is not resolved does not necessarily mean that fine structural details do not exist. It does mean that either we do not know how to prepare the surfaces so that these details are differentiated or else the separation is beyond the resolving power of the objective and the light. Negative results do not signify that our knowledge has not been augmented. So far as metallurgical work is concerned, it seems probable that the possibilities of the finest objectives now available are far beyond our ability to use them to best advantage. When we have learned how to improve our method for preparing and for etching specimens it is possible that an entirely new field of investigation will be open to us.

The photomicrographs accompanying this paper were taken by

the writer in the Bell System laboratories of the American Telephone and Telegraph Co. and the Western Electric Co., Inc., New York City. Some of the pictures are of the same subject but at progressively higher magnifications so that the effect of magnification may be evident. They were selected as representative of a large number taken in the course of our work throughout a period of several years. All were taken in connection with definite engineering problems in order that the knowledge derived might enable us to secure better materials.

Conclusion

In this paper it has been the author's object to show somewhat generally the possibilities of high-power metallography as applied to industrial problems. With each picture there is included a brief description and data pertaining to the specimen, its preparation, the optical parts, and the wave-length of the light used. In each case the magnification was determined accurately by means of a high-power stage micrometer.

THE EFFECT OF SILICON ON THE THERMAL CRITICAL POINTS OF STEEL

By F. L. Meacham

Abstract

The effect of silicon on the A1 point of steel is to raise the Ac1 point 28.1 degrees Cent. and the Ar1 point 28.9 degrees Cent. per cent of silicon. The effect on the A2 point of steels under 0.29 per cent carbon is to lower the point by 11.1 degrees Cent. per cent silicon. The carbon content of the steel apparently has a marked effect on the A2 point in ferro-silicon alloys. The A3 point is difficult to follow in silicon steels since silicon diminishes the intensity of the point very rapidly. A method employing the change in electrical resistance at the A3 point, points toward a possible method of following the transformation further than it has previously been followed.

Object of the Investigation

THE object of this investigation was to determine the effect of silicon on the thermal-critical points of steel. That is to say, to ascertain the position of the points A1, A2, and A3 in iron-carbon-silicon steels and to compare the position of these points with those of pure iron-carbon alloys.

History

This subject is one upon which comparatively little work has been done. The oldest authoritative reference which was found was that of W. Gontermann of Victoria University, Manchester. His work was performed principally by taking cooling curves of various samples, and by studying quenched specimens under the miscroscope. He states that his method of taking cooling curves was not a particularly sensitive one and that the only

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A thesis presented in partial fulfillment of the requirements for the degree of Bachelor of Science in Metallurgical Engineering at Case School of Applied Science, June 1923. Experimental work conducted in the Research Department of the National Malleable Castings Co., Cleveland, O.

transformation which he had been able to investigate thermally was that of the formation of pearlite, or the A1 point.

Charpy and Cornu-Thenard also did some work along this line, the results of which were published in Vol. XCI of the *Journal* of the Iron and Steel Institute in 1915. The following is a summary of their results.

Influence of silicon on the A1, A2 and A3 points:

They were able to confirm, as other observers had pointed out, that the A3 point rapidly decreases in intensity when the percentage of silicon increases, at the same time rising on the temperature scale. The temperature at which the A1 perturbation takes place rises with the silicon percentage, this point reaching, and then passing the A2 point while becoming gradually fainter. After reaching a given percentage of the metalloid and for a given rate of variation of the temperature, the A1 point completely disappears, and all the carbon of the steel is found in the state of graphite.

The A2 point falls gradually in the temperature scale as the percentage of silicon rises, losing little by little its intensity the while, but still persisting in a very clear manner in metals containing up to 7 per cent of the metalloid. At this percentage of silicon, the A2 point is the only abnormality which appears upon thermal investigation, in alloys containing low carbon, even when the rate of variation in temperature be sufficiently accelerated.

The most recent work which has been done on this subject, exclusive of the present investigation, is that of Howard Scott of the Bureau of Standards. His work in connection with ferrosilicon alloys was done on steel of about 0.45 per cent carbon content. The manganese averaged about 0.70 per cent. Ac1 is raised 21 degrees centigrade and Ar1 raised 18 degrees Cent. for each per cent of silicon added up to at least 3 per cent, while A2 is lowered 21 degrees Cent. for the same increment.

Description of Apparatus

Crucibles

A satisfactory crucible in which to melt the samples was a source of much trouble at the beginning of the experiment. The

crucible which was finally used and which gave good results was made by lining a graphite shell with magnesia.

Furnace

The furnace used for melting was a horizontal granular carbon resistance type.

Current to the furnace was supplied by a transformer at a maximum of 90 volts. Control of this furnace was accomplished by means of an induction voltage regulator connected into the power line, ahead of the transformer.

Casting

Casting was done in a box filled with ordinary molding sand properly tempered and packed. The test pieces were made about ½ inch in diameter, 2½ to 3½ inches long, depending upon the amount of material melted. These castings were allowed to cool in the sand. When cold they were removed, cleaned and machined, the turnings being saved for chemical analysis.

Transformation Point Apparatus

The equipment used for this purpose was a regular type transformation point recorder, as manufactured by the Leeds and Northrup company.

Electrical Resistance Apparatus for Locating A3

In an effort to locate the A3 point and follow it further than it had previously been followed in the iron-carbon-silicon alloys another method was tried. This method, suggested by H. A. Schwartz (modified from Honda), employs the principle that the A3 transformation is accompanied by a marked change in electrical resistance.

The specimens for use were machined into the shape of bars with a rectangular cross section ⅛ by ½ by 3¼ inches long. The samples examined, were joined at one end to a bar of Armco (nearly pure) iron of the same dimensions. The samples thus mounted were connected as shown in Fig. 1.

In Fig. 1, I represents a bar of Armco iron and S the steel sample. These two bars are joined at A, from which point a lead is taken to one side of the difference galvanometer of the transformation point apparatus.

Current is supplied by the battery B, which is conducted to the bars by iron wires connected to the samples at the points C and C^1. Another set of lead wires are connected to the specimens at the points E and E^1. These wires lead to the variable resistance R1 and R2. From the point F another lead is taken to the difference galvanometer DG.

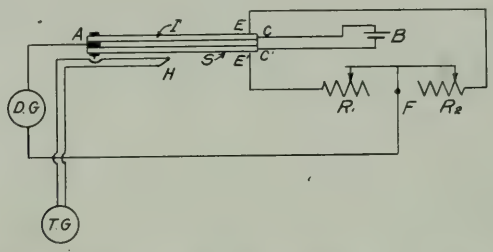

Fig. 1—Showing Method of Connecting Specimens for Obtaining Their Change in Electrical Resistance.

When the battery B is connected and the resistance R1 and R2 properly balanced, no curent will flow through the circuit F, DG, A. If the resistance of either bar, the Armco iron or the steel, changes, a current will flow through that branch of the circuit and thus deflect the galvanometer in a direction depending upon which bar changes resistance. Thus, when the apparatus so arranged and balanced, is heated through the critical range of one of the bars, a deflection will be produced in one direction. This deflection will be counteracted when the other specimen reaches its transformation point and changes resistance, provided that the resistance of both bars changes in the same direction.

The temperature of the specimen is measured by placing a thermocouple close to the specimen at the point H. This is then connected to the potentiometer of the transformation point equipment. By this procedure both the temperature and the change of resistance could be recorded directly upon the regular type of chart used with this equipment.

The type of curve which would be expected from this procedure is shown in Fig. 2. The slope of the line AB is due to a slow but constant heating of the specimen accompanied by a gradual and slightly differential change in resistance of the specimen. When the transformation point of one of the bars is

reached such as the point B, a change in resistance occurs which is accompanied by the corresponding deflection BC. When the transformation has completed itself the course of the curve will be along the line CD, practicaly parallel to, or in the same gen-

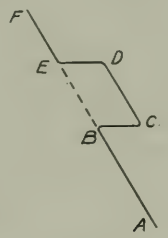

Fig. 2—Type of Curve to be Expected from Tests Made with Apparatus in Fig. 1.

eral direction as AB. When the transformation point of the second bar is reached, its resistance changes and is accompanied by the deflection DE. If these deflections should happen to occur at the same temperature and the amount by which the resistance changes be the same, no deflection would occur and we would have the straight line ABEF.

Upon repeated heating and cooling the deflection corresponding to the A3 point for the Armco iron should always occur at the same temperature. By using different steel samples with varying silicon content, the position at which the deflection due to the A3 point in the steel occurs will move up or down the temperature scale. Thus, by making a series of these curves it should be possible to trace the path of the A3 point as it changed its position, due to the silicon and carbon of the steel.

Detailed Account of Method of Procedure

The samples tested were prepared from Armco iron, ferro-silicon and washed metal, melted together in the proper proportion to give the desired chemical analysis. Four series of samples were selected, each series having a different carbon content, ranging from 0 to 0.75 per cent, namely 0, 0.25, 0.50 and 0.75 per cent. For each of these carbon percentages, samples were prepared with silicon contents approximately 0, 0.50, 1.00, 2.00, 3.00 and 4.00

per cent. Considerable difficulty was experienced in making specimens of the desired compositions.

When the calculated amounts of each material had been charged into the hot crucible and allowed to melt, they were

Table I

Chemical Composition and Thermal-Critical Points of Steels Tested

Carbon Per cent	Silicon Per cent	Critical Points—Degrees Fahrenheit Ac1	Ar1	A2	Sample Number
		Series-1			
0.26	0.07	1340	1300	1405	700
0.26	1.20	1400	1310	1395	24
0.10	5.00	1595	1530	1330	15
		Series-2			
0.38	0.39	1330	1305	1350	20
0.38	0.54	1335	1310	1350	19
0.34	0.63	1385	1310		705
0.38	2.03	1460	1360	1390	520
0.30	4.35	1640	1590	1350	540
		Series-3			
0.48	1.48	1400	1300	1370	18
0.47	2.25	1395	1250	1290	710
0.52	3.45	1510	1400	1380	14
0.44	3.90	1530	1440	1365	16
		Series-4			
0.64	1.80	1410	1390	1390	720
0.64	2.45	1475	1380		17
0.59	4.03	1510	1510	1220	740
0.58	0.66	1370	1310	1345	23
		Series-5			
1.32	0.01	1300	1330		10
0.72	0.25	1340	1300		21
0.94	0.45	1360	1305		11
1.02	1.00	1400	1400		12
		Series-6			
0.74	1.90	1445	1390	1415	13
0.70	1.92	1450	1370	1420	22

vigorously stirred with a soft iron wire and then allowed to remain in the furnace for about ten minutes, so as to insure thorough mixing of the different materials charged.

When ready to pour, the current was turned off from the furnace and the crucible removed with a pair of tongs. The liquid melt was then poured into a mold made with ordinary molding sand. All analyses are recorded in Table I.

Thermocritical curves were taken on all of the samples made. It proved impossible, however, to follow the A3 transformation with the transformation equipment, so it was decided that a series of cooling curves should be taken on liquid low carbon samples of different silicon content. This procedure was tried by melting up material of the desired composition and then

placing a thermocouple in the bath, the couple being protected by a fused quartz tube. This method did not prove to be a suc-

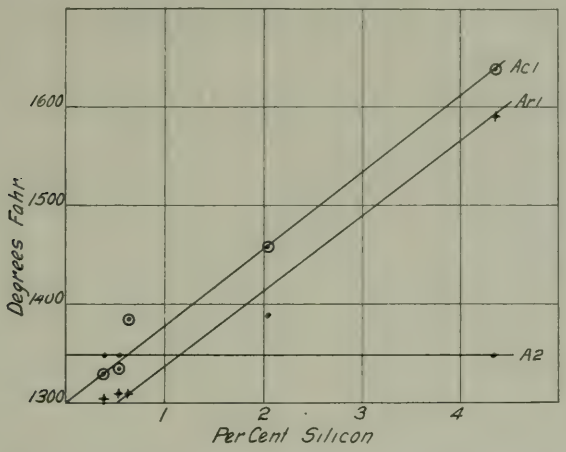

Fig. 4—Showing the Effect of Various Amounts of Silicon on the Critical Points of a 0.30 to 0.40 Per cent Carbon Steel.

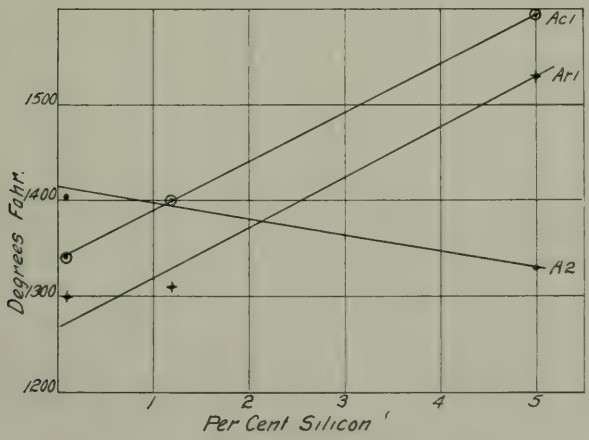

Fig. 3—Showing the Effect of Various Amounts of Silicon on the Critical Points of a 0.10 to 0.26 Per Cent Carbon Steel.

cess, due to the fact that the rate of cooling was too irregular even though precautions were taken to promote regular cooling. The results from these tests, when plotted, were meaningless for any of the points other than A1.

Discussion and Conclusions

In taking the data incorporated in the results of this investigation the location of the Ac1 and Ar1 points was taken at the

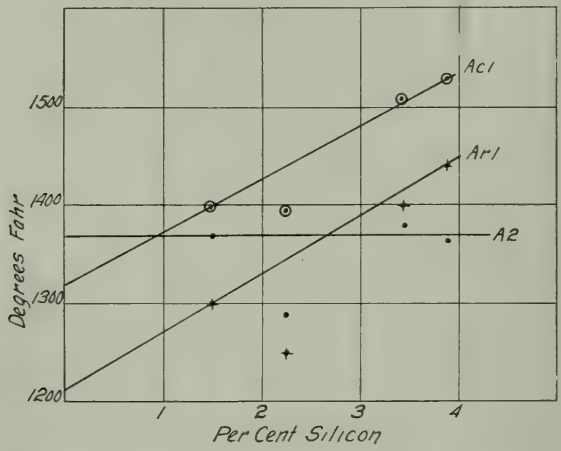

Fig. 5—Showing the Effect of Various Amounts of Silicon on the Critical Points of a 0.44 to 0.52 Per Cent Carbon Steel.

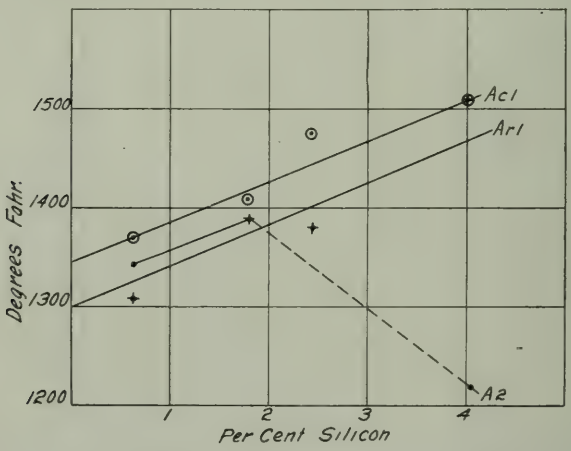

Fig. 6—Showing the Effect of Various Amounts of Silicon on the Critical Points of a 0.58 to 0.64 Per Cent Carbon Steel.

point at which the break in the transformation curve starts. In the interpretation of the A2 point, a different method or system was employed. Due to the characteristic shape of the A2 point

the peak of the break was taken as the temperature of the transformation. There is very little hysteresis in the A2 point, so, consequently, it often happens that the A2 transformation may

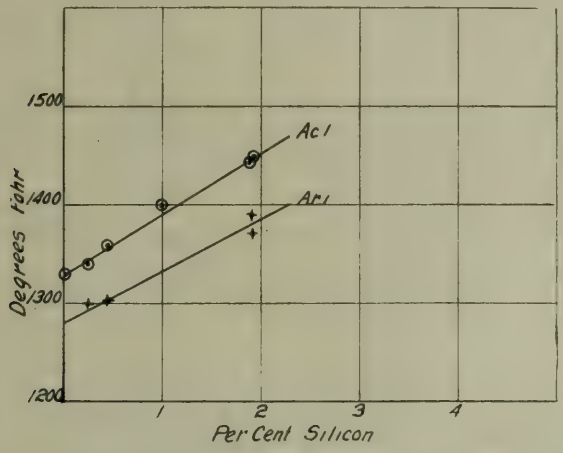

Fig. 7—Showing the Effect of Various Amounts of Silicon on the Critical Points of 0.70 Per cent Carbon Steel.

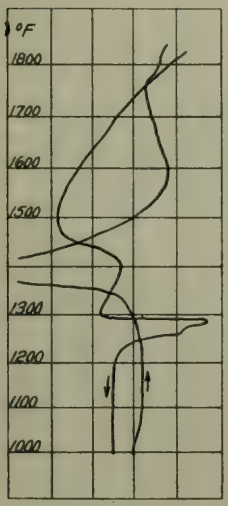

Fig. 8—Reproduction of Transformation Point Curve of a 0.26 Per Cent Carbon, 0.07 Per Cent Silicon Steel.

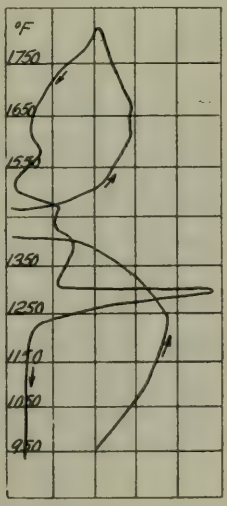

Fig. 9—Reproduction of Transformation Point Curve of a 0.26 Per Cent Carbon, 1.20 Per Cent Silicon Steel.

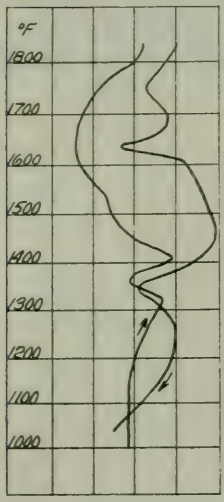

Fig. 10—Reproduction of Transformation Point Curve of a 0.10 Per Cent Carbon, 5.00 Silicon Steel.

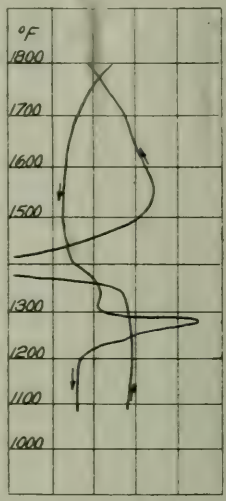

Fig. 11—Reproduction of Transformation Point Curve of a 0.38 Per cent Carbon, 0.39 Per Cent Silicon Steel.

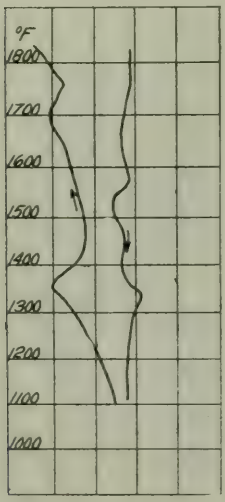

Fig. 12—Reproduction of Transformation Point Curve of a 0.30 Per Cent Carbon, 4.35 Per Cent Silicon Steel. Curve Smoothing out at High Silicon Content.

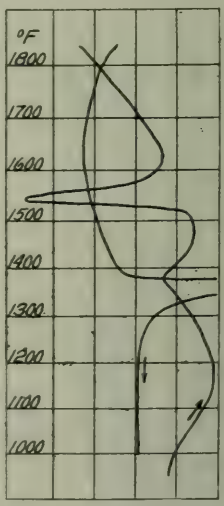

Fig. 13—Reproduction of Transformation Point Curve of a 0.52 Per Cent Carbon, 3.45 Per Cent Silicon Steel.

be hidden in the Ac1 transformation on the heating curve while on the cooling curve the Ar1 transformation will be lowered, due to hysteresis, sufficiently to show the A2 point. If the A2 point was obtained on both the heating and cooling curves it was found that the Ac2 point would be *slightly* above the Ar2 point. In such a case the mean of the two points was taken as the actual critical point.

A tabulation of the temperature at which the Ac1, Ar1, and A2 points occur is found in Table I. When these values are plotted as in Figs. 3, 4, 5, 6 and 7, the effect of silicon on the thermo-critical points is shown.

It was found that the A1 transformation remained a horizontal line in the Iron-Carbon diagram, but was gradually raised in proportion to the silicon content. The Ac1 point rose an average of 28.1 degrees Cent. for each per cent of silicon, while the Ar1 point rose 28.9 degrees Cent. for each per cent of silicon. If the average of the Ac1 and Ar1 points be taken as the position of the A1 point, and a line drawn through this average value, it will intersect the temperature ordinate at 1300 degrees Fahr. or 704 degrees Cent. This is the value for iron obtained from this work and differs from the temperature generally accepted for A1 by only 10 degrees Fahr. or 6 degrees Cent. This small discrepancy is well within the working limits of the apparatus and any personal error which might enter into the results. Figs. 8, 9, 10, 11, 12 and 13 show some of the types of curves obtained.

By the method of interpretation employed for the A2 points of the curves from samples included in Series 1, the effect of the silicon is to lower the point by 11.1 degrees Cent. This value is very close to the value noted by previous investigators with the exception of Howard Scott, whose work was performed on steels of about 0.45 per cent carbon.

The remaining series do not check Series 1 in regard to the lowering of the A2 point. Undoubtedly discrepancies of interpretation occur, due to the range of carbon content of the samples included in each series, inasmuch as the carbon does affect the position of the A2 points in steels. The variation in carbon content cannot be made to account for all the difference in Series 2, 3, and 4, because in these series the difference from Series 1 is too great for the small variation in carbon to produce.

In Series 4, the A2 point tends to rise somewhat as the silicon increases until 2.5 per cent is reached after which point it lowers rapidly. This break in the A2 point was also noted by Charpy in his work on the subject. A2 as noted in the graphs representing Series 2 and 3 is practically horizontal with perhaps a slight tendency to drop.

So far as this problem was carried nothing definite was learned about the A3 point except that with the addition of silicon, it becomes very faint and difficult to find. The method involving the change of electrical resistance points toward a possible method of following the transformation.

The author wishes to express his appreciation to all those who have, in any way assisted him with the work in connection with this investigation. Especially does he wish to thank H. A. Schwartz, director of research of the National Malleable Castings Company, for the privilege of working in his research laboratory, and for the many valuable suggestions made in connection with the problem. Likewise does he wish to express his appreciation to Prof. H. M. Boylston who so willingly co-operated with him in all ways.

(*Continued from Page 610*)

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The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 99. What is the effect of barium carbonate and sodium carbonate in carburizing compounds, on alloy carburizing boxes?

QUESTION NO. 100. What action results from the addition of varying amounts of aluminum and ferrosilicon to steel while casting?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 67. What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?

ANSWER. By S. A. Richardson, Department of Engineering, Lewis Institute, Chicago.

The ability of any medium to extract heat from a piece of steel depends upon a combination of certain physical and chemical properties. It is quite generally agreed that these properties are viscosity, boiling or volatilization point, thermal conductivity, density, specific heat, latent heat of vaporization and heat of (chemical) dissociation. The substance possessing the right combination of these properties will be a more drastic quenching medium than a substance not possessing this ideal combination. The actual temperature of the medium, within reasonable limits, may exert but little influence in such a case as outlined in this question.

QUESTION NO. 69. Is sulphur up to 0.10 *per cent detrimental to the quality and physical properties of an automotive steel?*

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

ANSWER. By S. A. Richardson, Department of Engineering, Lewis Institute, Chicago.

When specimens of steel are subjected to tensile stress they undergo a decrease in diameter, or cross section at right angles to the direction of the pull. The ratio, after rupture of the bar, between the area at the point of greatest decrease in diameter and

the original area of the specimen, determines the per cent reduction of area. It is a measure of the ductility of the steel.

QUESTION NO. 93. What are the more common methods of quenching ordinary taps? Are they quenched all over and the shanks drawn, or are they quenched only on the threaded portions; or are both the threaded portions and the tangs quenched, leaving the center portion of the shank soft?

QUESTION NO. 94. What are the most salient causes of the explosive disruption of many hardened steel articles?

ANSWER. By S. A. Richardson, Department of Engineering, Lewis Institute, Chicago.

The explosion, or sudden breaking of the steel is caused, of course, by internal stress, which apparently may be produced by two causes. The first condition is observed more often in pieces of considerable mass. It appears that the outer shell of the piece of quenched steel undergoes the changes occurring in the critical range and becomes set before the interior has accomplished these changes, so that the marked expansion that should take place is suppressed in the interior of the steel. The stress set up by the interior of the steel endeavoring to effect this volume change is usually sufficient to burst the piece. In most cases, this can be prevented by placing the piece in the drawing furnace or bath immediately upon its removal from the quenching tank, thus softening the exterior so that it will give without cracking. The same thing may often be done by withdrawing the quenched piece from the bath as soon as the steel is black, so that it may be tempered by its residual heat. The second condition may be due to a nonuniform quenching, nonuniform drawing, or quenching a nonuniformly heated piece. Thus—a properly quenched piece of steel—all martensite—if drawn over only part of its mass will rupture in the same manner. The explanation appears to be that the constituent produced by the drawing, say troosto-sorbite, has a different volume than the constituent of the untempered area, which we have said is martensite. Two

unequal volumes in a piece of steel will set up internal stress sufficient to produce rupture, or in a more ductile steel, to produce warping.

QUESTION NO. 95. What is meant by "self hardening" steels?

ANSWER. By Frank Garratt, superintendent, Latrobe Electric Steel Co., Latrobe, Pa.

In a general sense "self-hardening" steels are those which, by the addition of some element other than carbon become hard when cooled freely in air from, or above, their hardening temperatures.

From this definition it will be seen that "self-hardening" steels may cover a wide range of composition including particularly, certain chromium, nickel chromium, molybdenum chromium, and tungsten chromium steels, and certain combinations of tungsten, chromium, molybdenum, and vanadium. High-speed steel is the most common example of "self-hardening" steels.

While the definition given above may include a large number of steels, some tool steel manufacturers and users have in mind a certain distinct type of steel when the term "self-hardening" is used. This type of steel is the forerunner of the modern high-speed steel, and as compared with the latter is very high in carbon, low in tungsten, and free from vanadium. In certain cases molybdenum has replaced the tungsten addition.

This steel came into use soon after Mushet's discovery that tungsten in combination with carbon and manganese (and later chromium) produced the property of the steel becoming hard on cooling freely in air from the hardening temperature. Owing to this very unusual property, at that time, the steel was called "self-hardening."

As these early types were perfected, resulting in steels of changed compositions and greater cutting capacities, the term "high-speed" steel came into more general use, and the term "self-hardening" was retained to distinguish the early types of cutting tools from the more modern high-speed steels.

Some actual analyses of these early types of "self-hardening" steels are as follows:

Carbon	2.18	1.79	.98	1.42
Tungsten	8.80	7.87	8.75	none
Chromium	1.89	3.72	2.98	3.39
Molybdenum	none	none	none	3.41
Silicon	1.13	.15	.28	...
Manganese	2.24	.28	.39	...

It should be understood, of course, that the term "self-hardening" is used in a relative sense, since the sections treated naturally influence the rate of cooling, and the degree of hardness acquired (which must also be taken into consideration) is dependent to a certain extent upon such rates of cooling.

Steels that ordinarily are not classed as "self-hardening" might become hard on air cooling if the section is sufficiently small, while unusually large sections of some "self-hardening" steels may not become sufficiently hard on merely air cooling.

QUESTION NO. 96. Can the structure of a piece of steel be determined by the microscope applied to the fracture of a cross section, without polishing and etching the fracture, say of a stamping die 6 x 2 x 3½ inches, that has been hardened and broken in half, that is, are the different structural phenomena known as austenite, martensite, sorbite, ferrite, etc., so determinable?

QUESTION NO. 97. What degree of heat is required to change austenite to martensite, troosite, etc?

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

TRANSACTIONS
of the
American Society for Steel Treating

Vol. IV Cleveland, December, 1923 No. 6

OPPORTUNITY

ARE you ready when *Opportunity* knocks at your door? Will you know when *Opportunity* really knocks? Preparation for that time must be a continual process of observation, study and application of one's mental capacities along those lines in which he is best adapted. *Opportunity* is ever-ready and is almost constantly knocking, but in most instances we are not ready, and cannot acknowledge the call. Preparedness should be our watchword at all times, as it is only through being prepared, that we are able to accept outstanding opportunity as it is presented.

There are, of course, many types and varieties of opportunity. Most of us take advantage only of mediocre conditions of life. It is only through expending great effort in both mental and physical endeavor, that we can expect to arrive at an enviable position or station in life. Usually one gets out of life about what he puts into it, and likewise one's services are in demand in just about that proportion that he has made himself more valuable than his colleagues or co-workers. Initiative must be an outstanding factor. Those individuals who display a high order of initiative are selected and presented with that intangible something we call opportunity.

The study of personal success involves many attributes of a person. Success is attainable by all, but it cannot be attained without courage and work. The little things—the details, are of paramount importance. Do you ever ask yourself whether or not you do the little, minor details, well? If not, it would be well for you to inquire into this matter. Should you determine that, perhaps, you have been somewhat negligent, it would be well for you

to turn to a new leaf in your book of life, and resolve to give the details of your daily work, the attention that they really deserve. It is common knowledge that if the bricks in a wall are poorly made and poorly laid, there can be no other result but a weak structure.

The man who does a task only moderately well will be only moderately compensated. The man who does the task very much better than anyone else, will be compensated in proportion. The world is constantly looking for those who can do things better than anyone else can do them, and it is to those who are prepared to accept the opportunity as it comes, who will have the straight road to success.

Be prepared, and the opportunity for you to show your capacity will be ever-present.

THE BUSINESS SITUATION

WHEN the records of the year 1923 are entered in the annals of American business, the year will be described as one of prosperity just as surely, although not so emphatically, as 1921 will be remembered as one of depression.

In spite of the muddled conditions which have been prevalent in Europe for the past five years, and which still seem to be a long way from being settled, America has shown a healthy business growth especially in the past two years.

During the summer, declines appeared in a number of lines, but this condition has changed to one of gains, especially in the automobile production, building construction, copper, and other nonferrous metals. Stability and steadiness prevail.

Conditions in the iron and steel industry are not so encouraging, with prices falling, orders declining, and output tending downward. The mills are producing at about 80 per cent of capacity and the industry is permeated by a spirit of caution. However, with increases in railroad orders and the recent favorable earnings report of the United States Steel Corp., lend a favorable tone to the situation.

All in all, the general business forecast is that basic conditions are sound, and that for the next six months business prosperity will prevail.

WINTER SECTIONAL MEETING

THE winter sectional meeting will be held under the auspices of the Rochester Chapter of the Society on Thursday, Jan. 31, and Friday, Feb. 1, 1924 with headquarters at the Hotel Seneca, Rochester, N. Y.

The program for this meeting is as follows:

Thursday, January 31

11:00 a. m. Registration and Technical Paper, at Seneca hotel.
12:30 p. m. Luncheon, at Seneca hotel.
2:00 p. m.-5:00 p. m. Three Technical Papers.
6:30 p. m. Joint Banquet of Rochester Chapter of the American Society for Steel Treating and the Chamber of Commerce at the Chamber of Commerce building.
Toastmaster—Doctor Rush Rhees, president of the University of Rochester.
Speaker—Doctor G. K. Burgess, president of the American Society for Steel Treating, and director of the Bureau of Standards.
"Relation of the Government to Industry."

Friday, February 1

6:30 p. m. Joint Banquet of Rochester Chapter of the American Society for Steel Treating.

Plant visitation: I. L. Nixon, chairman of the committee, has arranged for visiting the following plants in the order named: Gleason Works, the Taylor Instrument companies; the Bausch-Lomb Optical company; the research laboratory of Eastman Kodak company.

A complimentary luncheon will be served to visiting members and guests in the private dining room at the Bausch and Lomb Optical company.

The morning and afternoon technical sessions, as well as the luncheon will be held at the Hotel Seneca, the headquarters for the meeting.

This meeting will be one of the best sectional meetings the society has held and the papers for the occasion are going to be

HOTEL SENECA
Winter Sectional Meeting Headquarters

well worth while. The complete list of speakers will be announced in the January issue of TRANSACTIONS.

Here is an opportunity for the members to again get together for the exchange of ideas and renewal of acquaintance, and every member should make every possible effort to be present.

Please make your hotel reservations early and directly with the hotel management, the rates for which are as follows:

Rooms equipped with	Single	Double
Hot and cold running water	$2.50	$ 3.50
Shower baths	2.50	4.00
Shower baths	3.00	4.50
Shower baths	3.50	5.00
Tub baths	3.00	5.00
Tub baths	3.50	5.00
Tub baths	4.00	6.00
Twin beds and shower baths		5.00
Twin beds and tub baths		7.00
Two double beds and tub bath (4 persons)		10.00

Parlors $3.50 and up, per day.

In making reservations, it is important that the hour of arrival be given, as reservations are not held after 10 p.m., except on special request.

Kindly make second choice, in the event your first choice of rate is not available.

INFORMATION OF INTEREST TO MEMBERS OF THE SOCIETY

THE board of directors of the American Society for Steel Treating at its regular meeting in Washington, unanimously voted to have a digest of the minutes of their meetings published

in future issues of the TRANSACTIONS. It is hoped the members at large will take greater interest in the work of their national officers and it is believed that this action will meet the hearty approval of the entire membership.

Your attention is, therefore, directed to the digest of the minutes of the November meeting published on the succeeding pages of this issue of TRANSACTIONS.

VOLUME IV OF TRANSACTIONS COMPLETED

THIS issue of TRANSACTIONS completes Volume IV. As previously announced, TRANSACTIONS will be issued in two volumes per year. Volume IV covers the period from July, 1923, through December, 1923. Volume V will include the period from January, 1924, through June, 1924. The index for Volume IV is now ready and copies may be obtained upon request. Address American Society for Steel Treating, 4600 Prospect avenue, Cleveland, O.

EDUCATIONAL ACTIVITIES OF THE CHAPTERS

THE special educational activities of a number of our chapters is indeed a most worthy and commendable endeavor. Among those chapters which are either fostering courses in metallurgy or metallography under their own supervision or in co-operation with local educational institutions are, Lehigh Valley, Philadelphia, Chicago, Tri City, Milwaukee and Cleveland. The Lehigh Valley and Pittsburgh chapters have offered prizes for the best paper written upon the subject of steel and its treatment, to be written during the current year by engineering students at Lehigh university, Carnegie Tech and the University of Pittsburgh. The Philadelphia chapter has awarded three scholarships to shop men for the evening course in metallurgy given at Temple university. The other chapters working in co-operation with local educational institutions are conducting evening courses for the benefit of their members. A very active interest has been shown in this work in all of these chapters, and it shows how the society may assist in the work of educating its co-workers.

REPORT OF THE MEETING
of the
BOARD OF DIRECTORS OF THE AMERICAN SOCIETY FOR STEEL TREATING

Meeting Held at the
Bureau of Standards, Washington, D. C., Friday,
November 2, 1923, at 10:00 a. m.
All Officers and Directors Present

AN UNAUDITED financial report of the fifth annual convention of the society, held in Pittsburgh, October 8-12, 1923, was presented. The report showed total receipts from all sources to be $38,848.48, while the expenditures amounted to $26,879.30, leaving an excess of income over expenditures of $11,969.18. It was pointed out, however, that this report did not carry the overhead for the remainder of the year until January 1, and that there were a few outstanding bills not yet received. Upon motion duly made and carried, the unaudited report was accepted and ordered filed.

Consideration was then given to the selection of a convention city for the sixth annual convention to be held in 1924. Invitations were received from New York, Boston, Atlantic City, Buffalo, Cleveland, Chicago, and Los Angeles. Inasmuch as four of the previous five conventions of the A. S. S. T. had been held in central or western territory, the board, by unanimous vote, decided that the 1924 convention should be held in Boston, unless the convention committee, to be appointed, should report otherwise; and that the dates for holding the convention should be decided by the convention committee after their investigation. The President then appointed the following convention committee: Chairman, Doctor Burgess; members, Messrs. W. S. Bidle, F. P. Gilligan, and W. H. Eisenman.

F. P. Gilligan was appointed by the Board as their representative on the local convention committees of the convention city.

The location for the sectional meetings for 1924 was then considered. Owing to the proposed location of the annual

convention in Boston, a rearrangement of cities for holding sectional meetings, as previously determined upon, was thought advisable. It was unanimously determined that the winter sectional meeting should be held in Rochester, N. Y., in January, and the spring sectional meeting be held in Tri Cities, the exact dates to be determined later.

The next item for consideration was the awarding of the Henry Marion Howe medal. The Final Awards committee submitted a report in which they recommended that no Howe medal be awarded for the year ending July 31, 1923. After some discussion, upon a majority vote, the report of the committee was accepted and the committee discharged.

President Burgess and past-president Lynch presented a report of their attendance at the Henry Marion Howe memorial service held in New York.

Consideration was next given to the appointing of committees as presented by President Burgess. The committees appointed by the President received the unanimous approval of the Board.

FINANCE COMMITTEE: Chairman, Dr. Zay Jeffries; members, Roy McKenna, J. M. Watson, J. V. Emmons and George L. Norris.

PUBLICATION COMMITTEE: This committee was approved, as at present constituted with the addition of two new members (J. L. McCloud and A. W. F. Green); the committee is as follows: Chairman, Prof. H. M. Boylston; Ray T. Bayless, vice chairman and secretary; members, Messrs. C. M. Johnson, A. H. d'Arcambal, S. C. Spalding, W. H. Laury, H. Freeman, E. E. Thum, E. W. Ehn, R. S. Archer, J. L. McCloud and A. W. F. Green.

MEETINGS AND PAPERS COMMITTEE: Chairman, L. D. Hawkridge; members, Messrs. H. C. Goodwill, C. E. McQuigg, Benjamin Shepherd, O. T. Muehlemeyer, and Ray T. Bayless, secretary.

CONSTITUTION AND BY-LAWS COMMITTEE: Chairman, S. M. Havens; members, Messrs. W. P. Woodside, H. J. Stagg Jr., Jerome Strauss, and H. Kenneth Briggs.

MEMBERSHIP COMMITTEE: Chairman, W. E. Blythe;

members, Messrs. Arthur Henry, Robert Schenck, and Sam Shagaloff.

It was moved and unanimously carried that there should be no Library committee appointed for the present year. However, the national secretary was instructed to send a letter of appreciation to Dr. J. Culver Hartzell, for his services as chairman of the committee in the past.

The next question taken up was that of the appointment of a Research committee as well as the field it was to cover. After some discussion it was moved and carried that a committee consisting of H. J. French, chairman, with Messrs. Brophy and Merica should be appointed to have a meeting and report back to the Board whether or not there was a field for a Research committee, and if so, what that field might be.

NOMINATING COMMITTEE: President Burgess, in co-operation with the Board then selected the following five chapters from which one member of the Nominating committee should be appointed by the chapter: Boston, Detroit, Schenectady, Cincinnati, and Tri City. It was understood, however, that this committee was not to be announced until January 1, 1924, so as to determine if possible, whether or not the new scheme for the nomination of national officers, as embodied in the new constitution might be made effective by having the new constitution and by-laws adopted in time for the newly constituted Nominating committee to have a meeting at the next annual convention.

The question of a Standards committee was next presented for consideration, and the recommendation made at the annual meeting that the name be changed from "Standards" to "Recommended Practice" committee, received the approval of the Board. R. M. Bird then gave the following scheme of organization of a Recommended Practice committee:

"The recommended Practice committee should consist of 7 to 9 members, whose work it would be to plan and actively expedite the work of the committee. This committee should meet about twice a year, and there should be a paid secretary to carry on the business of the committee. Such a committee would function in the following manner: As an

example, should an individual suggest that it would be well to established a recommended practice for the heat treatment of locomotive parts, the first information that the Recommended Practice committee should have is whether or not there is a real need for such a recommended practice. It would then be the duty of the secretary of the committee to develop whether or not there is that need. This work could be done either through visits, letter, personal contact, or by proper committees in the chapters. The results of this circularization would then come back to the Recommended Practice committee. If it is found that there is a real need for recommended practice on the subject under consideration, the committee would then appoint a sub-committtee and assign it this work. This sub-committee, in co-operation with the secretary, would collect and compile proper recommended practice on that subject. When the sub-committee's work is completed the report should be presented to the Recommended Practice committee and could be handled as follows:

1. The report tentatively accepted and the sub-committee discharged.

2. The report might be referred back to the sub-committee for further consideration.

3. The report could be dropped.

If the report was tentatively accepted and the sub-committee discharged, the report should then be referred to the membership of the society through the chapters, or by a special committee in the chapter appointed to consider such matters. If, then, the report comes back from the membership with no serious objections or corrections, it then comes out as a tentative recommended practice of the society for a period of one year. At the end of the specified time, the tentative recommended practice should come back to the membership of the society, either by letter ballot or before the annual meeting, and if the report is approved, it would become a recommended practice." Mr. Bird further added that the supervision of the data sheets, as well as indicating the subjects on which data sheets should be written, and acting as a clearing house for their final approval, could well be a portion of the work of the Recommended Practice committee. It was

felt that such a committee when properly organized would have an evolutionary effect in producing valuable recommended practices, and would develop quite rapidly after the work was started. It was thought, further, that as the membership at large realized the scope of the committee and the work it is capable of doing, they themselves will initiate subjects, and even prepare recommended practices for the consideration of the committee.

The Board was very favorably inclined toward the matter of an organization as proposed by Mr. Bird, and it was unanimously agreed to organize a committee on recommended practice along the lines indicated.

W. S. Bidle, chairman of a committee appointed at the meeting of the Board on October 9th, reported that the committee considered it advisable to recommend the employment of a man to act as secretary to the various national committees, and to perform such other functions as might properly be determined. Upon motion properly made and unanimously carried, this report was accepted and it was decided to employ such a man. President Burgess then appointed the following committee with full power to act: Messrs. W. H. Eisenman, W. S. Bidle and Dr. Zay Jeffries.

No definite appointments were made by the President for members on the Recommended Practice committee, with the exception of the appointment of J. Fletcher Harper as chairman.

It was moved and unanimously carried that a digest of the meeting of the Board should be published in the first following issue of TRANSACTIONS, and also that the chairman of the Finance committee should prepare a quarterly unaudited statement for publication in TRANSACTIONS in order that the membership may be thoroughly conversant with the work of the Board of Directors, as well as the financial condition of the society.

It was moved and unanimously carried that the following resolution be adopted:

> "RESOLVED, that we hereby acknowledge the members of the Society hereinafter named, as authorized to handle the banking affairs and to deposit and withdraw moneys from whatever bank

the Finance committee may designate upon checks signed by any two members of three names hereafter given. It shall be necessary, however, that one signature of the two names on the checks to withdraw must be that of the treasurer or secretary. The names of members authorized to sign checks for withdrawal or deposit are Dr. Zay Jeffries, national treasurer; W. H. Eisenman, national secretary; and J. V. Emmons, member of the Finance committee."

It was moved and unanimously carried that the bonds of the secretary and treasurer for $25,000 each, be continued, and that the members of the Finance committee authorized to sign checks should be bonded for $2500 each; the bonds to continue in the custody of the President.

The following resolution was presented, and upon motion properly made and carried, it was adopted:

"Recognizing the universal need for a set of generally accepted Heat Treatment Definitions, the directors of the A. S. S. T. do hereby RESOLVE: that the adoption of heat treatment definitions properly belongs to and should be fathered by the American Society for Steel Treating, and that the Recommended Practice committee is hereby directed to take this matter actively in hand."

The secretary then gave a report with reference to the progress of the data sheets and informed the Board that the first installment of this material would be mailed about the first week in December. The Board further authorized the secretary to place the name of the member of the Society on the binder when such binders were purchased through the national office.

A wire was received from Colonel A. E. White conveying his kind wishes and greetings. The secretary was authorized to send the following wire to the Colonel:

"The Board of Directors at their regular meeting in Washington express appreciation for the receipt of your wire, and extend to you kind greetings. They realize the great contribution you have made to the progress of the Society, and note with regret your first absence from the meetings of the Board."

It was moved and unanimously carried that the Board authorize the Secretary to write a letter of appreciation to J. V. Emmons for his services as treasurer. The letter is as follows:

My dear Mr. Emmons:

I have been authorized by the Board of Directors at their

regular meeting in Washington on November 2nd, 1923, to express their great appreciation for the valuable services you have given the society as national treasurer during the past two years.

They are conscious of the untiring effort and careful thought you have given to the duties of your office and the financial standing of the society at the present time is due, in no small part, to your eminent services.

They realize how impossible it is to adequately express their appreciation by written words, but they do sincerely wish you to know that as officers and directors of the society, representing the members, your aid in the advancement of the society will always be considered of the highest merit.

Yours very truly,
(Signed) W. H. EISENMAN.
National Secretary.

S. M. Havens, chairman of the Constitution and By-Laws committee submitted a tentative report of progress in making changes in the new constitution as recommended by the members at the last annual meeting. This report was accepted as a report of progress.

Requests were received from the Los Angeles chapter for a national officer to visit their chapter some time during the winter, and at the same time organize chapters of the society in San Francisco, Portland and Seattle.

A communication was also received suggesting the advisability of sending an A. S. S. T. representative to England during the next spring in order to make an intensive study of English technical societies as well as to attend the meetings of the Institute of Metals, the British Iron and Steel Institute, and also the British Empire's Industrial Exposition.

Upon motion properly made and unanimously carried, the secretary was instructed to secure estimates of the cost of the suggested trips and report at the next meeting of the Board.

In order to comply with the laws of Ohio in which the directors of the society elect their own officers, it was moved and unanimously carried that the individuals as indicated by the members as their choice for officers should be the officers and directors of the Board.

The meeting adjourned at 5:30 p. m.

CHARACTERISTICS OF SOME MANGANESE STEELS

By Jerome Strauss

Abstract

This paper consists in part of a review of previously published data on manganese steels and in part of a new metallographic survey (supplemented by mechanical tests) of a portion of the iron-carbon-manganese system.

Following a brief history of the development of iron-manganese alloys, an account is given of those manganese steels that have found commercial application. Their mechanical, electrical and magnetic properties are briefly considered.

The relation of microstructure to mechanical properties in a series of steels prepared in an induction furnace, forms the basis for a discussion of the constitution of these alloys and of possible improvements in some of the commercial combinations. In conclusion, directions in which manganese may prove useful as an alloying element, are indicated.

Introduction

THE history of modern alloy steel development begins with Sir Robert A. Hadfield's researches into the effect of large additions of ferromanganese to soft steel. There had been previously some inquiry, of course, into the properties imparted by the introduction of manganese, nickel, chromium and other elements but these either were unsystematic, or were discontinued (at least in the case of manganese) upon the first appearance of undesirable characteristics in the product, with increasing percentages of the added element. Credit must, therefore, be given Hadfield for his broader vision. His pioneering where others saw merely useless expenditure of effort opened a field, which in the 40 years since the announcement of his success, has been widely settled yet cultivated only in scattered spots. Our knowledge of alloy steels is still in its infancy.

A paper presented, in part, before the Philadelphia chapter of the Society. The author, Jerome Strauss, is material engineer, United States Naval Gun Factory, Washington, D. C.

Returning to the specific question of manganese steels, we find perhaps the first mention of the nonmagnetic iron-manganese alloys by Rinman, who in 1774 observed that the white, brittle metal obtained by fusing equal parts of gray pig iron and manganese oxide was not attracted by a magnet. About 1830, David Mushet prepared alloys containing up to 30.0 per cent manganese using manganese oxide, iron oxide, cast iron, charcoal and fluxing agents. He also noted the failure of the high-manganese alloys to be attracted by a magnet but was apparently dealing with alloys too high in carbon to observe the facts disclosed by Hadfield's later work. Subsequent development in this sphere yielded one outstanding feature, namely the application of ferromanganese (first produced commercially in 1865) to the steels made by the Bessemer and Siemens processes, to provide materials that would bear hammering and rolling; this application resulted from the work of Robert Mushet. Earlier experimenters had made small additions of manganese ore to crucible steel but the relative importance of their discoveries is slight.

About 1875, the Terre Noire works in France experimented with increases in the manganese content of structural steels, exhibiting the results of these experiments at the Paris exposition in 1878. The steels made contained from 0.45 to 0.60 per cent carbon and 0.52 to 2.42 per cent manganese. It was stated that the 1.3 per cent and 2.0 per cent manganese alloys cracked on oil quenching and that the steel carrying 2.4 per cent of this element could not be hammered or rolled. Hadfield's experiments and later production of such steels suggest that these failures were due to unsuitable raw materials or manufacturing processes or both, rather than to composition (the company reported 0.06 to 0.07 per cent phosphorus present, with sulphur content not mentioned though probably low). At about the same time, two German producers experimented with manganese steels and as their results also appeared to confirm the detrimental effect of manganese above 2.0 to 3.0 per cent, the Terre Noire company discontinued its labors in this direction. It should be noted, however, that one of the German steel works made alloys up to 4.4 per cent manganese with 0.66 per cent carbon, by additions of crucible-melted ferromanganese to Bessemer steel and the other, by manufacture directly in the crucible, made steels up to 11.4 per cent manganese,

but with a carbon content of 2.42 per cent. This unfortunately high carbon, as will be shown later, probably accounts for the failure of this particular set of experiments.

Because of these and probably many unpublished failures, Hadfield's courage and success and his discovery of the toughening treatment for the high-manganese alloys, justify the recognition they have received. A few tensile tests selected from the results of his early work[1] are given in Table I. These values were obtained on 1-inch rolled or forged bars, turned to 3/4-inch diameter for a gage length of 8 inches, except as noted in the table. Among

Table I
Effect of Manganese and Carbon on the Tensile Properties of Steel

Bar No.	Composition C	Mn.	Condition as Tested	Tensile Strength lbs. per sq. in.	Elongation in 8 in. per cent
1	.20	.83	As Rolled	75000	31.5*
2	.40	2.30	As Rolled	126600	6.5*
3	.40	3.89	As Rolled	85100	0.5
4	.52	6.95	As Forged	56900	1.5
5	.52	6.95	Water Quenched	52000	1.6
6	.50	7.90	Oil Quenched	66700	7.0
7	.61	9.37	Air Cooled	84400	15.6
8	.61	9.37	Oil Quenched	85600	14.8
9	.61	9.37	Water Quenched	87100	14.8
10	.85	10.60	Air Cooled	91500	17.2
11	.85	10.60	Oil Quenched	94300	18.8
12	.85	10.60	Water Quenched	91600	17.2
13	.85	12.29	As Forged	88000	3.5
14	.85	12.29	Water Quenched	145000	50.0
15	1.10	12.60	As Forged	88000	2.3
16	1.10	12.60	Water Quenched	120600	27.3
17	.92	12.81	Air Cooled	108200	19.5
18	.92	12.81	Oil Quenched	129000	32.8
19	.92	12.81	Water Quenched	136200	36.7
20	.85	13.75	Water Quenched	145400	50.7
21	.85	13.75	Water Quenched, Reheated and slowly cooled	102600	6.2
22	.85	14.01	Air Cooled	107300	14.1
23	.85	14.01	Oil Quenched	123200	26.6
24	.85	14.01	Water Quenched	150300	44.4
25	1.10	14.48	Water Quenched	142000	37.5
26	1.55	14.16	Water Quenched	100400	14.1
27	1.24	15.06	Water Quenched	135600	31.2
28	1.54	18.40	As Forged	114700	0.8
29	1.54	18.40	Water Quenched	119200	10.1
30	1.60	19.10	As Forged	115400	0.8
31	1.60	19.10	Water Quenched	131100	4.6
32	2.10	21.69	As Forged	80600	8.6
33	2.10	21.69	Water Quenched	74600	10.9

Note:—All quenching and air cooling made from "white heat."
* Bars 1⅛-inch diameter between 10-inch gage marks.

the facts disclosed by these tests, the following are of particular interest and the reasons for some of them will be briefly indicated later:

(a) The increase in tensile strength and decrease in ductility

1. R. A. Hadfield—Manganese in its Application to Metallurgy and—Some Newly Discovered Properties of Iron and Manganese. *Proceedings* of Institution of Civil Engineers. 1887-1888.

with small increases in manganese and carbon and the subsequent decrease in both up to 0.5 per cent carbon and 7.0 per cent manganese.

(b) The increase in tensile strength and elongation of quenched bars, beginning at 0.5 per cent carbon and 8.0 per cent manganese and reaching a maximum between 12.0 and 15.0 per cent manganese.

(c) The uniformity of tensile properties in the 9.4 and 10.6 per cent manganese steels with various cooling rates after heating, provided such rates are fairly rapid (bars 7, 8, 9 and 10, 11, 12).

(d) The marked effect of rate of cooling after heating on the strength and ductility of the 12.8 and 14.0 per cent manganese steels (bars 17, 18, 19 and 22, 23, 24).

(e) The decrease in strength and elongation in the tougher steels with increases in carbon content (bars 14, 19, 16 and 24, 26, 25).

Commercial Manganese Steels

(*a*) *Low Manganese Steels*

Due, probably in part, to failures of early Bessemer rail steels containing over 1.0 per cent manganese and to Hadfield's original statement that with 2.5 to 7.5 per cent, the resultant steels were unfit for commercial application, but undoubtedly more directly due to sad experiences in attempting to apply drastic quenching to eutectoid steels having slightly more than normal amounts of this element, there has grown upon most practical men a distrust of all steels containing 1 per cent or more. Because water quenching will often crack eutectoid steels of such composition is not sufficient cause for maintaining that steels of 1.0 to 2.0 per cent manganese are brittle; the possibility of the heat-treatment given not being suited to the steel, structural inequalities due to previous mechanical and thermal treatment and defects traceable to steel-making processes must also be considered. The suitability of the heat treatment is of particular importance and is equally applicable to the present case as to other tender alloy steels. In fact 1.0 to 2.0 per cent manganese, while increasing the strength and hardness of the carbon steels, and in some cases rendering them sensitive in heat treatment does not impart brittleness and should not limit their commercial use.

In the realm of very soft steels, the work of Lang[2] is of considerable interest and some of his mechanical tests are listed in Table II. Although the author did not describe his manipulations in detail and used steels of varying phosphorus content (0.04 to 0.11 per cent) and clearly indicated the absence of pyrometric control in his heat treatments, the results, nevertheless, have much value. In the rolled or annealed bars there is a marked increase in proportional limit and tensile strength without appreciable loss in ductility or notched-bar impact resistance up to 1.77 per cent manganese. After quenching, the same is true up to 1.27 per

Table II

Mechanical Properties of Low Carbon Manganese Steels

Series	Steel No.	Composition C	Mn	Prop. Limit lbs. sq. in.	Tensile Strength lbs. sq. in.	Elongation % in 8"?	Reduction of Area %	Brinell	Impact ft. lbs. sq. in.
A—	1	.11	.29	46000	62600	27.9	53.5	11	1100
As Rolled	4	.10	.79	49200	64500	27.9	65.9	119	1580
	6	.10	1.27	54300	71300	27.9	68.1	132	1250
	8	.10	1.77	57900	82500	25.9	54.7	156	1190
	11	.09	2.47	63400	103000	18.8	39.4	211	130
E—	1	.11	.29	43200	56900	31.5	70.0	113	1460
Annealed	4	.10	.79	45100	59700	30.3	70.1	118	1520
	6	.10	1.27	46600	65000	30.2	72.6	132	2050
	8	.10	1.77	48300	73900	27.4	72.3	159	1970
	11	.09	2.47	52300	108200	15.4	53.1	218	660
C—	1	.11	.29	42900	78700	19.6	61.0	147	1120
Quenched	4	.10	.79	49600	85000	14.1	56.1	157	1420
	6	.10	1.27	61600	107500	15.2	48.2	230	870
	8	.10	1.77	86000	155000	9.0	44.6	273	700
	11	.09	2.47	92200	166600	3.1	18.9	...	550

cent and would probably hold good up to a higher percentage, were slight drawing resorted to. Also the relative increase in strength due to quenching is very much greater with the higher manganese proportions.

Thus, to some extent, manganese can replace carbon in increasing the strength of plain steels and this principle has found frequent application; there is usually an appreciable increase in ductility. In general, it would appear desirable in soft steels to obtain the increased strength in untreated parts by an increase in carbon, but to use manganese where the steels were to be applied in the heat-treated state.

These 1.0 to 2.0 per cent manganese steels of low carbon content are not, however, suitable where good magnetic or electrical

2. G. Lang—Uber den Einfluss des Mangans auf die Eigenschaften des Flusseisens—*Metallurgie*, 1911.

properties are desired. Lang's steels, with the 2.2 per cent manganese increase, showed a gradual rise in electrical resistance totaling over 60 per cent (independent of heat treatment), and an increase in both coercive force and hysteresis, which in the quenched series amounted to 330 and 140 per cent respectively; simultaneously the permeability was appreciably lowered.

Several years ago, Abbott[3] published the results of some experiments with a structural steel containing a relatively high proportion of manganese; some of his results, grouped in Table III, are worthy of close study. In the annealed condition the man-

Table III

Comparison of Physical Properties of Carbon, Nickel and Manganese Steels

	Chemical Analysis						
	C	Si	S	P	Mn	Ni	Cu
Carbon	.34	.030	.029	.014	.54		
Nickel	.34	.188	.019	.019	.55	3.17	.05
Manganese	.34	.009	.025	.047	1.61	....	.02

	Tensile Properties					
	Elastic Limit	Tensile Strength	Elongation in 2"	Reduction Area	Brinell	Heat Treatment
Carbon	36600	67250	32.0	51.0	120	Annealed
Nickel	55000	81850	31.2	59.0	153	
Manganese	61150	87850	29.9	58.5	150	
Carbon	72000	110000	18.0	50.0	192	Water
Nickel	147000	152000	17.5	60.0	243	Quenched
Manganese	153000	158000	15.5	44.5	250	Drawn 800°F
Carbon	64000	93000	23.5	60.5	163	Water
Nickel	115000	120000	22.0	65.0	207	Quenched
Manganese	118000	126000	18.0	50.5	214	Drawn 1000°F
Carbon	59000	78000	29.0	68.0	152	Water
Nickel	88000	95000	28.5	68.5	158	Quenched
Manganese	91000	96000	23.0	58.5	172	Drawn 1200°F

ganese steel is far superior to the carbon steel and possesses an elastic limit and a tensile strength somewhat greater than those of the nickel steel, along with equal hardness and very slightly lower ductility. After water quenching and drawing (holding 30 minutes) the manganese steel still possesses for the same drawing temperature, an advantage over the nickel steel in elastic limit and tensile strength, although the ductility of the former material is somewhat lower. Tests of oil-quenched bars as well as data on notched-bar toughness and resistance offered to alternating stresses would have greatly increased the interest that attaches to these figures. There has been some commercial use of small forgings of this composition and of plates with somewhat lower carbon con-

3. R. R. Abbott—A Comparison of the Properties of a Nickel, Carbon and Manganese Steel Before and After Heat Treatment. *Transactions*, American Society of Mechanical Engineers, 1915.

tent but not to the extent which the author considers economically desirable from a consideration of these and other tests. To mention specific uses, steels of 0.25 to 0.35 per cent carbon and 1.10 to 1.40 per cent manganese have at times been used to replace 0.35 to 0.45 per cent carbon steels with normal manganese, in drop forgings for automotive and similar service. Sheets of the same or higher manganese, but lower carbon content have been used for motor car and also railway construction but this particular application has been almost entirely confined to European countries.

A 0.50 per cent carbon steel containing over 1.20 per cent manganese has been reported [4] as having been satisfactorily employed for small arms rifle barrels and is still in use. It may be of value to call attention to Bellis' findings in comparing this steel with one of similar carbon content but with normal manganese (0.65 per cent). It appears that, in heat-treated parts of small cross section, increasing the time at the drawing temperature, caused in both steels a 25 per cent increase in ductility, but accompanying it a 4 to 5 per cent drop in proportional limit and tensile strength for the normal steel, with but 1/2 per cent decrease in these values for the high-manganese steel; the latter value is, of course, less than the difference usually found in duplicate heat-treated bars. In the light of these tests, heat-treatment modification in the case of Abbott's steels might have been even more favorable to the high-manganese alloy. Steel of the same composition as used in these rifle barrels has found successful application for a number of years in cylinders for the transportation of various gases under high pressure.

In the direction of somewhat higher carbon contents, an outstanding example of the use of manganese above 1 per cent is in spring steels of about 0.60 per cent carbon and 1.15 per cent manganese. It has been contended by manufacturers and others that this material is not amenable to hardening by the user, and therefore, its major application has been as "tempered" wire in small diameters for springs for automobile and also general household upholstery. In spite of such contentions, the United States Navy has for a number of years used this steel up to 3/4-inch diameter for helical springs to carry maximum stresses intermediate between those for which carbon steel and those for which the more ex-

4. A. E. Bellis—Time Effect in Tempering Steel, *Transactions*, American Institute of Mining Engineers, 1918.

pensive and stronger alloy steels are used. This material has been made by either the acid or basic open-hearth process to a composition of carbon—0.55 to 0.65 per cent and manganese—1.00 to 1.25 per cent. After oil quenching and drawing these springs have successfully withstood all service stresses for which they were designed as well as those rigorous inspection tests applied to gun recoil springs, such as clamping solid for periods up to 48 hours and repeated rapid compression from free length to almost solid length 100 or more times; in the latter test a steam hammer has been used for load application.

In the eutectoid range, steels of 0.80 to 0.95 per cent carbon with manganese 1.00 to 1.75 per cent and with or without small additions of vanadium or tungsten and chromium have been unusually successful for intricate dies and other cutting tools and also gages where a combination of hardness and freedom from appreciable dimensional changes in heat treatment is necessary. Given correct forging and avoidance of careless heat application in treatment, there is no danger of cracking in oil-hardening these steels and, though not generally recommended, water-quenching is frequently successfully practiced.

Some years ago the author found that a steel of 0.80 per cent carbon and 2.00 per cent manganese was particularly suitable for use as shear blades in cold cutting of steel bars, having a greater service life under similar conditions than any carbon steel tried or chrome-vanadium steel of equal carbon content. No difficulty was experienced in hardening blades of this material even in masses weighing 500 pounds.

Apart from these forged or rolled materials, there has been frequent mention in the literature of steel castings containing manganese in excess of 1.0 per cent. Prominent among these is the report of Hall, Nissen and Taylor[5] giving a summary of tests taken from several years' production of castings of this composition. Most of the steel castings to which these authors refer were water quenched and then drawn at temperatures of 1150 degrees Fahr., or higher. Comparisons of steels of about 0.22 per cent carbon and 1.0 to 1.5 per cent manganese with 0.50 per cent carbon steels containing about 0.65 per cent manganese show for

5. J. H. Hall, A. E. Nissen and K. Taylor—Heat Treatment of Cast Steel, *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol LXII (1920), page 353.

equal tensile strength (80,000 to 85,000 pounds per square inch) an approximate increase of 15 per cent in elastic limit, 25 per cent in elongation and over 100 per cent in reduction of area; impact resistance by the Fremont method, although varying widely according to the manganese content, was two to four times as great. Some remarkable results were also given for a cast Bessemer steel containing 0.36 per cent carbon and 2.42 per cent manganese; with 25 per cent additional tensile strength the shock resistance equalled that of the 0.50 per cent carbon steel to which reference has just been made.

(*b*) *High Manganese Steels*

Ternary steels containing from 3.0 to 7.0 per cent of manganese have found no commercial application and with the higher proportions are not likely to be widely used as long as present manufacturing limitations, which enforce a minimum carbon content for any desired manganese percentage, must continue. Beginning, however, with 8.0 per cent and from this up to 16.0 per cent of manganese, steels have been prepared and very extensively used, both as castings and forgings, which possess a number of peculiar and interesting properties. These are the steels which were developed by Hadfield's researches and have since been known under the single term "Hadfield's manganese steel" or more commonly "manganese steel." Although the variation of manganese over this broad range along with the necessary (and sometimes undesirable) carbon variations, produce alloys of somewhat different properties, these effects will be discussed later, leaving for immediate attention only those generally characteristic of the entire group.

Many of the peculiar properties of these alloys are explained by two metallographic features, namely (a) their 100 per cent austenitic constitution when properly heated and quenched and (b) the precipitation of dark-etching acicular constituents under certain conditions of composition and thermal treatment. To the first condition is due the absence of magnetism, the moderate hardness, the high tensile strength, the high ductility and the low elastic ratio. These properties "manganese steel" possesses in common with the austenitic nickel steels and most other single-phase solid-solution alloys. Under the influence of cold work, however, it hardens

more readily than any of these alloys and it is this peculiarity which has caused its application wherever extreme resistance to wear was a prime requisite and slight surface flow with the accompanying dimensional change prior to obtaining effective wear resistance, was not a drawback. This same property has, however, limited its use inasmuch as the hard surface produced by abrasion

Table IV
Quenching Tests of High Manganese Steel
Carbon Content 1.10-1.15 *per cent*
Manganese Content 11.00-11.50 *per cent*
½" diameter. Bars heated to 1700°F. cooled at the rate of 100°F per hour, and quenched in water from the temperature indicated

Test No.	Temperature Degrees Fahr.	Elongation Per Cent	Breaking Stress lbs. sq. in.
1	1700	51.6	153800
2	1650	56.7	156700
3	1600	61.2	153950
4	1550	64.2	153200
5	1500	44.8	137200
6	1450	31.0	120450
7	1400	15.1	93370
8	1350	15.7	88750
9	1300	10.5	84120
10	1250	7.8	78060
11	1200	4.6	73950
12	1150	4.5	76940
13	1100	4.5	78040
14	1050	3.1	71220
15	1000	2.7	71625
16	950	1.5	68070
17	900	1.4	74440
18	850	1.5	80000
19	800	1.2	75290
20	750	0.5	69570
21	700	0.8	72500

develops also in most machining operations so that although it can be cut[6] such procedure is decidedly uneconomical. It was the ease of indentation (the Brinell hardness averages about 200) combined with the development of this surface condition that led Hadfield to describe the steel as possessing a "peculiar hardness" combined with "a special kind of softness." This extreme ductility and softness is such that, unlike the behavior of most steels, cracks once started in austenitic manganese steel of about 12.0 per cent manganese are propagated only with great difficulty, even under impact.

The second structural condition noted above is responsible for the extreme brittleness of these alloys when cooled slowly from a high temperature and the brittleness induced by heating to relatively low temperatures as well as the difficulty of obtaining a ductile

6. Machining is rendered somewhat easier by the use of liquid mixtures or solutions possessing great cooling ability as well as lubricating qualities or by certain heat treatments, the effects of which must be removed after machining is completed.

metal of small grain size with certain chemical compositions. The temperatures at which the sharp changes in tensile properties occur and the values that may be expected from rolled high-manganese steel have been clearly shown by Potter,[7] some of whose results are reproduced in Tables IV and V. In the series of bars quenched from successively lower temperatures the lowering of the tensile

Table V
Quenching Tests of High Manganese Steel
Carbon Content 1.10-1.15 *per cent*
Manganese Content 11.00-11.50 *per cent*
¾" diameter bars heated for sixty minutes at the temperature indicated and quenched in water

Test No.	Temperature Degrees Fahr.	Elongation Per Cent	Breaking Stress lbs. sq. in.
1	500	57.6	166500
2	500	53.0	169300
5	600	63.5	176000
6	600	55.0	163100
7	650	15.6	128000
8	650	21.7	137700
9	700	3.6	138200
10	700	1.6	116300
41	1500	23.5	139000
42	1500	26.7	142600
43	1550	57.4	155500
44	1550	52.8	154300
45	1600	42.4	162900
46	1600	42.5	161200
47	1650	65.0	147800
48	1650	63.8	145900
49	1700	62.1	143200
50	1700	58.9	139400
53	1800	56.5	133400
54	1800	53.2	132100
55	1900	44.1	123700
56	1900	42.0	121200
59	2100	35.7	93200
60	2100	40.9	99200
61	2200	17.3	80600
62	2200	21.7	79200

values takes place shortly after passing 1550 degrees Fahr. In the series quenched from successively higher temperatures, maximum strength and ductility are obtained at this same temperature. This temperature would regulate the conditions of rolling, if the resultant product were finished by quenching after the last pass. In Table V, the decrease in tensile values on reheating above 600 degrees Fahr. would indicate this as a maximum temperature for such operations as shrinking of forgings or castings on shafts, bushings, etc. The progressive decrease in strength above 1600 degrees Fahr. and in ductility above 1700 degrees Fahr. also indicate the undesirability of heating to too high a temperature for quenching; nevertheless, temperatures considerably above these have been advocated by some manufacturers. Furthermore, not only

7. W. S. Potter—Manganese Steel with Especial Reference to the Relation of Physical Properties to Microstructure and Critical Ranges. *Transactions*, American Institute of Mining Engineers, 1914.

quenching from a high temperature but also quenching from the proper temperature after cooling from the high temperature, results in poor tensile properties. Potter[8] found that cooling 3/4-inch diameter bars from 2100 degrees Fahr. at 100 degrees Fahr. per hour to various temperatures, followed by water quenching, yielded low strength and ductility at any quenching temperature, the values at 1600 degrees Fahr. being 79,510 pounds per square inch tensile strength and 25.4 per cent elongation. Similar behavior has been found in most other steels.

The combination of high tensile strength and high elongation in those steels of Tables IV and V that are in their best structural condition, is most unusual. In the use of certain so-called "merit-values" which involve the product of the tensile strength and elongation in fixing the order of superiority of structural metals, the author knows of no material that would excel "manganese steel." These values are not unusual for bar stock of relatively small size, and test bars taken from the head of heavy rails, which frequently are not quenched from the optimum temperature, commonly give values of 125,000 pounds per square inch tensile strength with 30 per cent elongation in two inches although ordered to a specification of 100,000 pounds per square inch and 20 per cent elongation.

As previously noted there are many points of similarity in the characteristics of the austenitic manganese and the austenitic nickel steels. But there are many differences, among which may be briefly mentioned the fact that the nickel steels possess marked resistance to many corroding influences whereas the resistance of the high manganese alloys is only slightly greater than that of carbon steel. The more interesting contrasts are in the hardness and magnetic properties as affected by various degrees of cold-working and by temperature changes. The surface hardening of "manganese steel" by abrasion has already been mentioned. In the progress of a tensile test, severe cold-working occurs, and in the case of "manganese steel," a Brinell hardness increase from 223 to 540 at the point of rupture, has been recorded.[9] The same authors observed for high-nickel steel a maximum change

8. Loc. Cit.

9. R. A. Hadfield and B. Hopkinson—the Magnetic and Mechanical Properties of Manganese Steel, *Journal* of the Iron and Steel Institute, 1914, and Researches with Regard to the Non-Magnetic and Magnetic Conditions of Manganese Steel, *Transactions*, American Institute of Mining Engineers, 1914.

of from 180 to 340. Accompanying this hardness was the development of a distinct magnetic condition in the nickel steel, although the hardened manganese steel showed only a mere trace of magnetism.

On heating at certain moderate temperatures "manganese steel" shows, with increasing time and temperature, an increase in hardness and also the presence of considerable magnetism. These changes, however, do not parallel one another. According to Hadfield and Hopkinson[10] high hardness (above 350 Brinell) becomes evident after several hours exposure at 750 degrees Fahr., whereas moderate magnetism is not obtained until similar exposures at 930 degrees Fahr. are used. A maximum hardness of 495 was obtained after 48 hours at 1020 degrees Fahr. and maximum magnetism after 600 hours at 930 degrees Fahr. Along with the magnetic effects is found a decided decrease in the difficulty of machining. It is also noteworthy that the magnetic qualities obtained in the above manner, practically disappear after one hour of heating at 1380 degrees Fahr. Such changes did not occur in high-nickel steels with heating periods up to 96 hours between 570 and 1290 degrees Fahr. Long exposure to liquid air temperature produced no appreciable hardness change and no magnetic effects in the manganese steel, whereas such temperature caused in the nickel steel, a very decided increase in the specific magnetism with a definite, though small increase in hardness (180 to 250, of which about 25 may have been due to the change of temperature alone, exclusive of structural changes).

In the manufacture of "manganese steel" it has been observed that the metal, as poured, is very fluid, (its melting range is about 2300 to 2450 degrees Fahr.) being more like cast iron than steel, and that it sets quickly, but with considerable liquid-to-solid contraction. In fact, the high losses due to piping of this metal were a strong factor in the development of the modern inverted, hot-top ingot mold. Another important property, from the producer's viewpoint, is the low thermal conductivity. This has enforced unusual care in maintaining soaking pit temperatures, at time of charging, close to that of the incoming ingot and also in insuring thorough soaking at the rolling temperature (2100 to 2150 degrees Fahr.) to avoid serious loss through ingots breaking in the blooming mill.

10. Loc. Cit.

Further, it has limited the thickness of the walls of castings to about 6 inches due to the difficulty of obtaining a satisfactory quenching effect in thicker sections.

It should be mentioned that these high manganese steels have a low electrical conductivity as well as a low thermal conductivity. Completely austenitic alloys of 1.0 per cent carbon and 12.0 to 14.0 per cent manganese offer a resistance to the flow of an electric current approximately 30 times as great as that of copper. On this account these alloys, soon after their discovery, were used in the form of resistance wire but the high temperature coefficient of electrical resistance combined with drawing difficulties due to rapid wearing of dies, prevented widespread use for this purpose.

Microstructure and Mechanical Properties

To illustrate the structural characteristics of a series of steels with increasing carbon and manganese contents and demonstrate the relationship of microstructure to mechanical properties a series of small ingots were prepared and subjected to a number of tests. The steels for these ingots were melted in an Ajax-Northrup high-

Table VI
Chemical Analysis of Manganese Steel Ingots

Ingot No.	Chemical Composition C	Si	S	P	Mn
469	.03	.11	.027	.003	5.88
470	.04	.16	.027	.007	8.61
630	.05	.38	.034	.009	16.35
444	.45	.05	.035	.015	3.58
443	.48	.08	.039	.025	8.72
442	.46	.10	.041	.018	14.39
449	.78	.16	.022	.019	1.86
448	.78	.18	.032	.017	4.40
446	.81	.22	.024	.013	8.87
450	.94	.14	.030	.015	12.68
445	1.20	.31	.020	.028	4.62
447	1.27	.19	.020	.016	8.68
632	1.22	.30	.029	.017	12.40
631	1.85	.18	.042	.013	4.26

frequency furnace, the charge being made up of Armco iron, crucible-melted carbon tool steel, carbon-free manganese, high-grade 80 per cent ferromanganese and washed metal in the proportions necessary to produce ingots of the desired composition. The raw materials were melted in an open crucible and as soon as completely molten and thoroughly agitated by the action of the induced current, were poured into cast-iron molds. The resulting ingots, approximately 1 1/4 inches square and 7 inches long were cut transversely into two equal lengths; this was just sufficient to avoid the pipe in the lower portion, in those ingots having the

Table VII

Tensile Properties of Forged Manganese Steels

Bar No.	Ingot No.	Composition C	Mn.	Heat Treatment (deg. Fahr.) Anneal	Quench	Draw	Prop. Limit lbs. per sq. in.	Tensile Strength lbs. per sq. in.	Elong. per cent	Reduction of Area per cent	Fracture
X-2	469	.03	5.88	1700 fce. cool			65080	115000	1.3	1.3	Sq. Silky Large Crack
X-1	469	.03	5.88	1700 fce. cool	1750 Water		87700	143400	12.1	42.0	Ang. Crack
X-4	470	.04	8.61	1700 fce. cool			87700	150600	1.7	2.6	Sq. Fine Gran.
X-3	470	.04	8.61	1700 fce. cool	1750 Water		99030	152800	2.0	3.3	Sq. Gran.
X-30	630	.05	16.35	1700 fce. cool			28300	104500	16.6	13.5	Sq. Gran.
X-31	630	.05	16.35	1700 fce. cool	1750 Water		34000	119500	40.0	49.5	.6 Cup
X-10	444	.45	3.58	1600 fce. cool			62200	123000	20.4	44.3	Ang.
X-9	444	.45	3.58	1600 fce. cool	1500 Oil	1100 Air	135800	157000	17.0	46.6	Star
X-8	443	.48	8.72	1600 fce. cool			39000	128000	1.7	2.6	Sq. Gran. & Fib.
X-7	443	.48	8.72	1600 fce. cool	1650 Water		37000	74000	1.7	2.0	Sq. Gran.
X-6	442	.46	14.39	1600 fce. cool			31100	101100	16.3	19.0	Sq. Gran.
X-5	442	.46	14.39	1600 fce. cool	1650 Water		31100	109600	18.3	22.6	Sq. Fine Gran.
X-20	449	.78	1.86	1600 fce. cool			53750	128700	10.8	13.5	Sq. Gran.
X-19	449	.78	1.86	1600 fce. cool	1450 Oil	1100 Air	144300	170 00	14.2	33.3	Sq. Silky .6 Cup
X-18	448	.78	4.40	1600 fce. cool			59400	139300	5.4	6.6	Sq. Fine Gran.
X-17	448	.78	4.40	1600 fce. cool	1450 Oil	1100 Air	127300	178000	3.3	4.0	Sq. Fib.
X-14	446	.81	8.87	1600 fce. cool			79200	163500	1.1	6.7	Broke in Thds.
X-13	446	.81	8.87	1600 fce. cool	1650 Water		42400	92600	12.1	20.2	Sq. Silky
X-22	450	.94	12.68	1600 fce. cool			34000	111700	1.7	2.7	Sq. Gran. & Fib.
X-21	450	.94	12.68	1600 fce. cool	1650 Water		45200	145700	47.1	39.2	Ang.
X-23	445	1.20	4.62	1600 fce. cool			53750	129400	4.6	5.3	Sq. Silky
X-11	445	1.20	4.62	1600 fce. cool	1650 Water		42400	67200	3.3	8.5	Sq. Fine Gran.
X-12	445	1.20	4.62	1600 fce. cool	1650 Oil 1400 Oil	1100 Air	121500	169500	2.9	2.6	Sq. Star
X-16	447	1.27	8.68	1600 fce. cool			96100	175400	1.3	1.3	Sq. Silky
X-15	447	1.27	8.68	1600 fce. cool	1650 Water		45300	96300	7.9	14.1	Sq. Fine Gran.
X-32	632	1.22	12.40	1600 fce. cool			36800	128700	3.7	3.3	*Sq. Silky
X-33	632	1.22	12.40	1600 fce. cool	1650 Water		53750	137000	20.0	22.5	*.6 Cup
X-34	631	1.85	4.26	1600 fce. cool	1650 Water		48000	87750	3.3	5.2	*Sq. Gran.
X-35	631	1.85	4.26	1600 fce. cool	1980 Air 1650 Water		48000	96750	3.3	3.9	*Sq. Gran.

* Broke in Points.

greatest pipe depth. A slice 1/2 inch thick was taken from the lower end of the upper half and samples cut from it for the study of the microstructure in the cast state. The lower half was forged to a 3/4-inch octagonal bar and short lengths from this used for microscopic examination after which the remainder was forged to 1/2-inch diameter and cut into tensile test specimens.

Heat treatments were all performed in an electrically heated muffle furnace, both microscopic specimens and tensile bars being maintained at the annealing or quenching temperature for 15 minutes, and at the drawing temperature for 30 minutes. Microscopic examination of the cast metal was on surfaces transverse to the

Table VIII
Brinell Hardness of Manganese Steels

Ingot No.	Composition C.	Mn.	Cast: As Cast	Annealed	Quenched	Q. & Drawn	Forged: As Forged	Annealed	Quenched	Q. & Drawn
469	.03	5.88	277	207	302	196	269	248	286	207
470	.04	8.61	293	321	311	255	286	302	302	241
630	.05	16.35	196	196	207	217	241	196	1 6	217
444	.45	3.58	286	228	460	311	512	228	512	293
443	.48	8.72	332	340	321	375	302	3 0	321	3 4
442	.46	14.39	217	196	207	217	255	212	223	21?
449	.78	1.86	302	241	555	311	286	241	652	31
448	.78	4.40	302	269	460	340	302	255	477	34 0
446	.81	8.87	163	418	187	444	387	387	196	477
450	.94	12.68	166	269	187	217	217	321	187	202
445	1.20	4.62	351	269	187	364	444	269	187	364
447	1.27	8.68	212	444	217	477	241	418	226	477
632	1.22	12.40	255	364	255	361	269	364	241	340
631	1.85	4.26	444	364	286	387	512	340	255	387

axis of the ingot and of the forged bars on surfaces parallel to the direction of forging. After photographing, these same surfaces were used in making the Brinell hardness determinations, all such tests being obtained with the 3000-kilogram load. The Brinell values are given in Table VIII. The tensile bars, 1/2-inch diameter, when heat-treated, were ground to 0.30 inch in the 2.20-inch pulling section; the 1/2-inch threaded ends were turned or ground. The proportional limit was determined by extensometer on a 2-inch gage length, but in computing elongations, a gage length equal to four times the diameter was used; such lengths had been marked prior to testing at several locations along the pulling section. The results of these tensile tests are given in Table VII.

The constitutional diagram of the carbon-manganese steels, as determined by Guillet,[11] for forged and air-cooled samples is shown in Fig. I. It will be observed that for very low carbon

11. L. Guillet—Etude Industrielle des Alliages Metalliques, Paris, 1906.

contents, the steels are pearlitic up to 5.0 per cent manganese, and the same in the case of 1.0 per cent carbon and up to 2.0 per cent manganese; also that with very low carbon, 13.0 per cent of manganese or with 1.0 per cent carbon, about 6.0 per cent of manganese renders the alloy austenitic; further, that above 1.0 per cent carbon, steels of the intermediate range contain no martensite.

The first alloy of the series, ingot 469, is in Guillet's transition zone; the structures produced by various heat treatments are shown

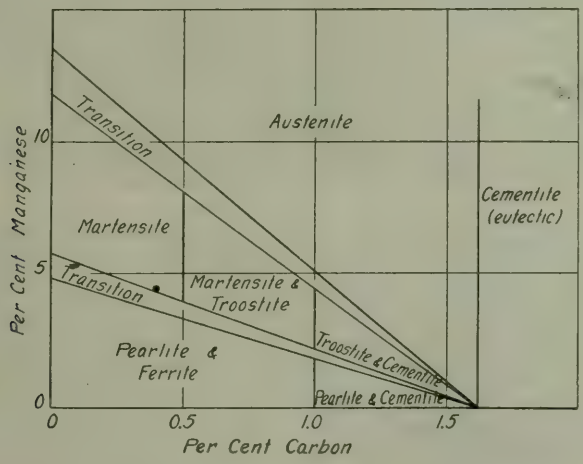

Fig. 1—Structure of Forged and air-cooled Manganese Steels.

in Fig. 2. The untreated and quenched specimens are decidedly martensitic in structure; after drawing, this acicular structure is still present, though less prominent, (some small areas in Fig. 2(h) resemble troostite) while after annealing the appearance of the etched samples is similar to that of a fine-grained iron. Unfortunately this one ingot had a very poor surface, the defects being deeper than first appreciated; this has detracted from the value of the tensile tests, both of the bars showing longitudinal cracks at the fracture; rupture was premature in each case. On a steel of similar composition, Arnold and Knowles,[12] reported a tensile

12. *Engineering*, Vol. 92, page 478.

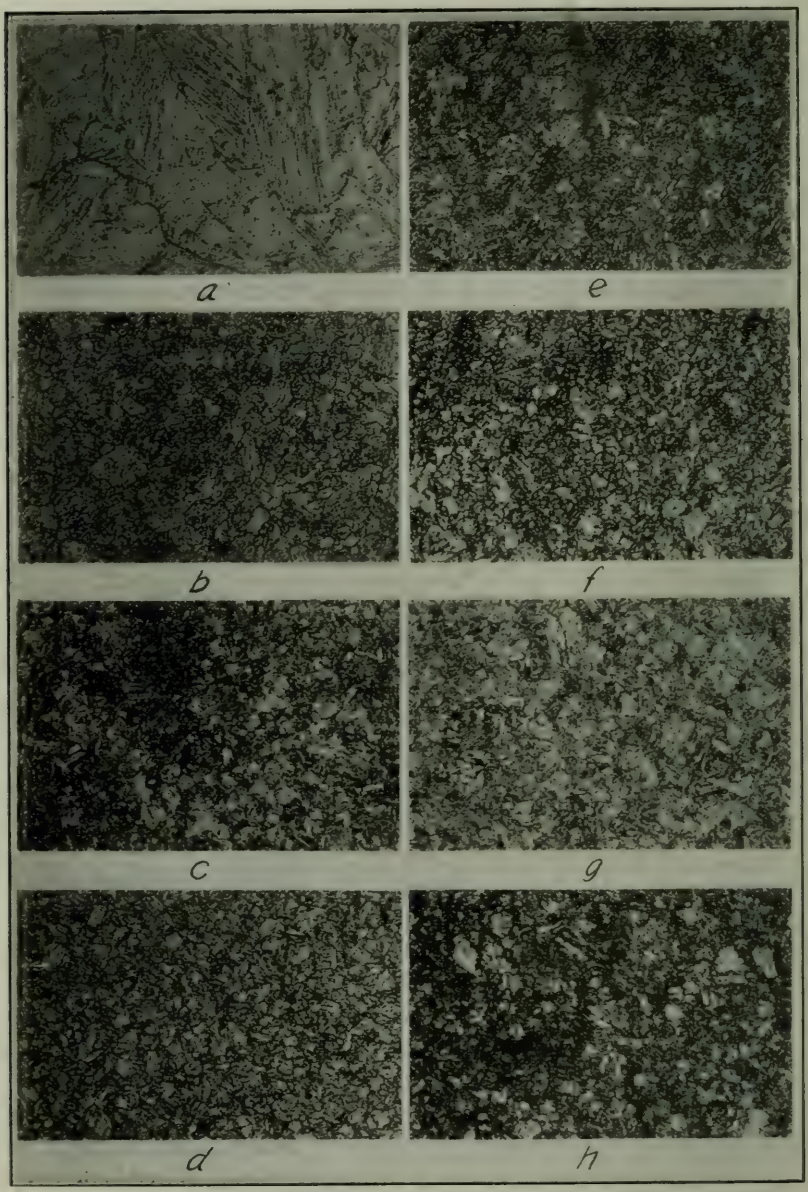

Fig. 2—Carbon, 0.03 per cent; manganese, 5.88 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1700 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1750 degrees Fahr. (15 min.) water quenched; (d) and (h) 1750 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

strength of 147,000 pounds per square inch with an elongation of 28.5 per cent after a very slow anneal (three-day cooling period); they also found that the resistance to alternating stress was good in the annealed state but very poor after quenching. In the present instance it is believed that sound bars would have shown comparable values, but it is also probable that alternating stress tests would have been more favorable to quenched samples of the authors' steel, if it is possible to judge of this from the tensile and hardness data.

The microstructure of the low carbon 9.0 per cent manganese steel is shown in Fig. 3. Martensite is the predominating constituent although photographs (a) and (c) give the appearance of some austenite while the annealed and the quenched and drawn specimens show areas similar in appearance to troostite. The reason for the existence of the austenite is apparent and is supported by the hardness determinations, but the explanation of the presence of troostite is not clear, unless perhaps due to areas low in manganese resulting from the usual concentration variation during rapid solidification. These dendritic formations have persisted through the heat treatments in most of the cast specimens and at times in the forged ones also. This interpretation does not account for the hardness of the quenched and drawn specimens being less than that of any others but does satisfactorily explain the increase in proportional limit on quenching an annealed bar.

The 16.0 per cent manganese low-carbon alloy (Fig. 4) shows in the cast form a very decided dendritic structure which has persisted through the forging operation to a greater degree than in the case of any of the alloys prepared. The matrix in each case is austenitic, the dendrites being a low-carbon martensite due undoubtedly to manganese segregation occurring during freezing of the molten metal. Long soaking at moderately high temperature would be required to efface this heterogeneity. The physical tests show the usual characteristics of an austenitic structure—low hardness, low proportional limit, relatively high tensile strength and considerable ductility.

In the microstructure of the medium-carbon 3.5 per cent manganese steel, there are no constituents that are not common. Nevertheless, it should be noted that with only 0.45 per cent carbon, this steel contains but very little free ferrite (the few small

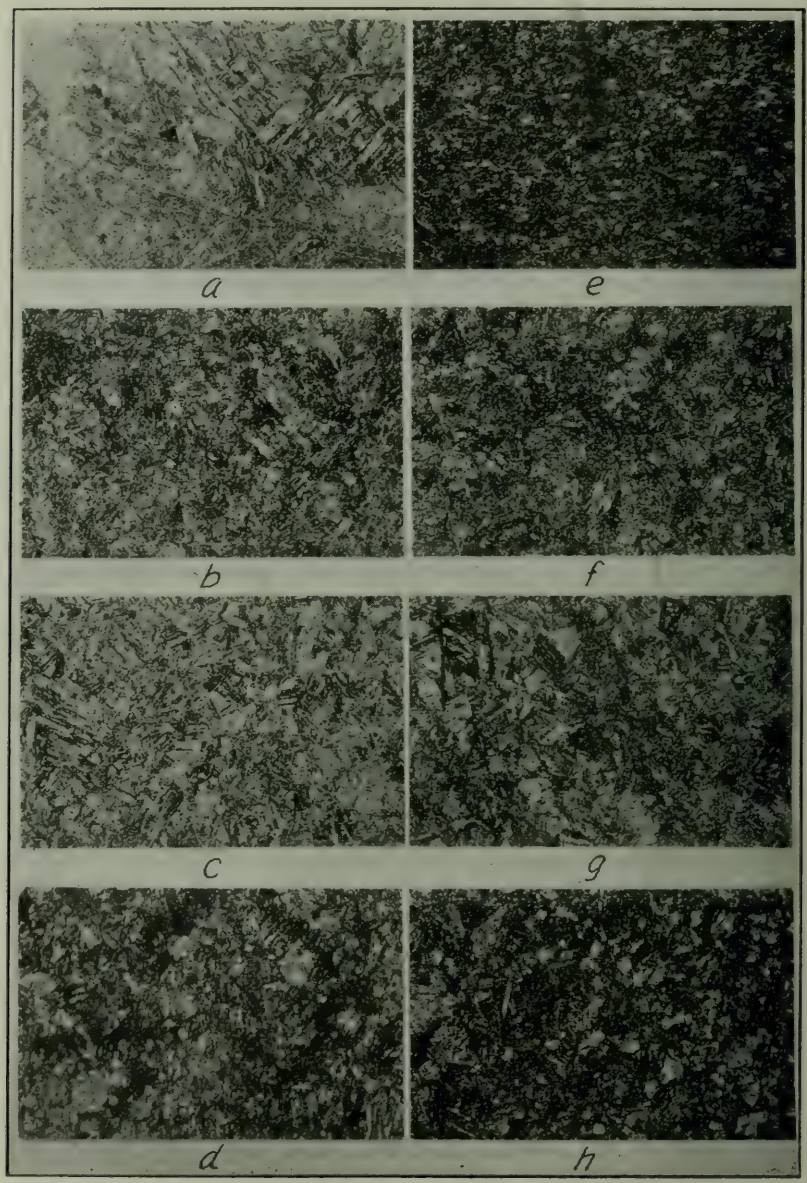

Fig. 3—Carbon, 0.04 per cent; manganese, 8.61 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1700 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1750 degrees Fahr. (15 min.) water quenched; (d) and (h) 1750 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

patches are almost obscured by the lighter of the pearlite areas); presumably with this amount of manganese the eutectoid point lies somewhere between 0.55 and 0.60 per cent carbon. Particular attention is invited to the fact that this steel is *not* brittle. Its properties in the annealed state are good although it is perhaps somewhat harder than might be desired for free machining. The heat-treated alloy shows an excellent combination of properties—high proportional limit, good ductility and the "star" fracture so common to the stronger types of alloy steels, particularly the nickel-chromium combinations.

Ingot 443 (Fig. 6) lies in Guillet's upper transition zone. In photographs (a), (b), (d), (f) and (h) the dark masses are troostite and the groundmass a mixture of austenite and martensite. For these low-magnification photographs which were used to illustrate the general conformation of the structural components, it was not always possible to etch in such manner as to define both austenite and martensite without destroying the outlines of the troostite and at the same time merging the latter with the martensite. Fig. 6 (b) approaches closest to the desirable condition of etching; here the three constituents are clearly visible, while in (c), (e) and (g), austenite and martensite only are present. These specimens are all quite soft because of the presence of the austenite, but the poor tensile test results are readily anticipated from the hard constituents in the microstructure.

The alloy containing 0.50 per cent carbon and 14.0 per cent manganese is entirely austenitic; its structure is in no wise changed by simple heat treatments. The tensile properties are good, although the proportional limit is very low and the elongation much less than would be expected from a consideration of the proportional limit along with hardness and constitution.

Coming to a consideration of the higher carbon steels, ingot 449 shows no structural indications not found in simple carbon steels, with the possible exception that a eutectoid steel is obtained in the presence of this amount of manganese, with a somewhat lower carbon percentage than is indicated by a study of the plain carbon steels. The quenched specimens naturally show coarse-grained martensite due to the high quenching temperature employed. Again it should be noted that this metal is not brittle, particularly after heat treatment. The quenched and drawn bar reported in

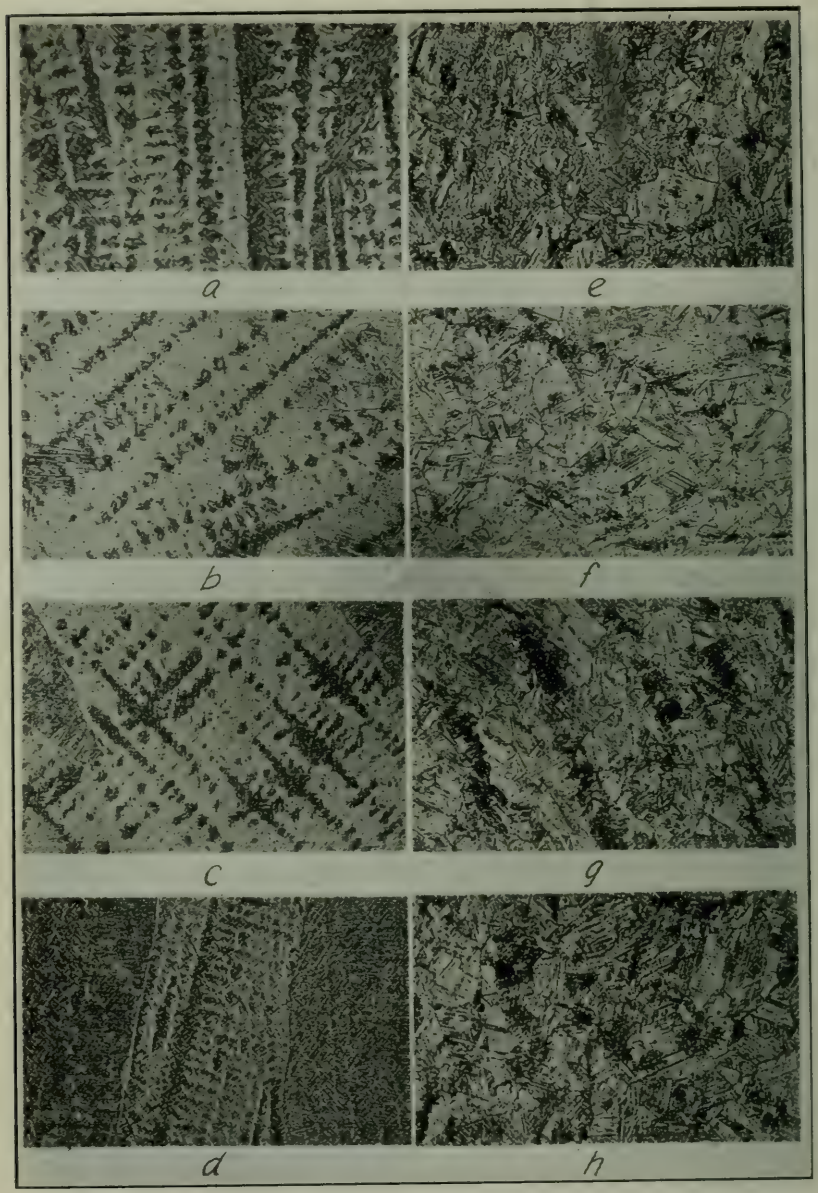

Fig. 4—Carbon, 0.05 per cent; manganese, 16.35 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1700 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1750 degrees Fahr. (15 min.) water quenched; (d) and (h) 1750 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

Table VII, when compared with carbon steel of eutectoid composition, shows for equal strength and ductility a proportional limit approximately 25 per cent higher.

The 0.78 per cent carbon steel containing 4.40 per cent manganese consists of martensite and austenite as cast, but troostite and austenite upon cooling in air after forging. On annealing, the structure is a mixture of pearlite and sorbite containing small areas of ferrite; these may be due to negative segregation of carbon in the branches of the dendrites which is not completely removed by forging. Quenching develops a rather homogeneous mixture of austenite and martensite which when drawn reverts to a condition closely resembling that of the annealed state but containing in place of pearlite some troostite not distinguishable in the photographs. Tensile properties are such that this steel would serve no useful purpose—at least from a structural viewpoint.

Ingot 446 (Fig. 10) is austenitic as cast; incidentally, in this photomicrograph, the primary dendritic structure and its independence of the secondary crystal boundaries is very pronounced. The forged specimen consists of patches of austenite and nodules of troostite in a martensitic ground mass. Annealing produces a coarse structure of troostite in a matrix of austenite and martensite. On quenching, the alloy becomes 100 per cent austenitic, the grain size being unusually small, while after reheating at 1100 degrees Fahr., troostite again is formed although more finely divided and in greater amount than after annealing; the cause for this is to be sought not only in the temperature but also the rate of cooling in each operation. The physical tests reflect the hardness of the troostite-martensite-austenite mixture and show also that the fine-grained austenite of this low manganese content has, in comparison with other austenitic steels about to be described, a lower strength and ductility.

With over 12.0 per cent manganese and 0.94 per cent carbon, a steel is produced that as cast is entirely austenitic, (Fig. 11); as forged, however, there are in addition to austenite, patches of troostite and dark etching narrow grain boundaries. In the annealed state the matrix is still austenite, containing patches of troostite but the grain boundaries are not entirely troostitic, there being portions which react toward etching reagents exactly as does the cementite of carbon steels. Quenching yields a completely austenitic material, which in the forged condition reproduces

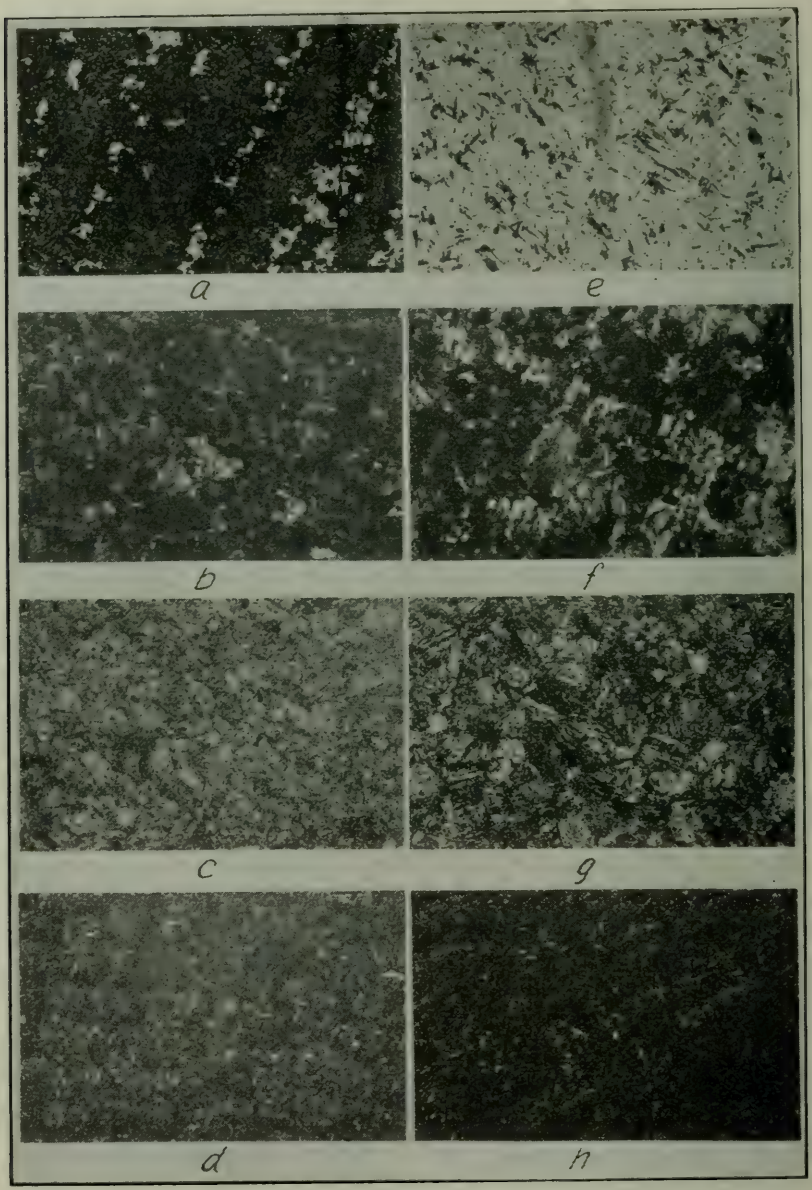

Fig. 5—Carbon, 0.45 per cent; manganese, 3.58 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

quite well the physical values reported by Hadfield[13] and by Potter.[14] The slightly lower values for the author's steel may undoubtedly be ascribed to the very low cross-sectional reduction in forging which amounted to about 10 to 1; this is considerably lower than for similar commercial steels. Drawing the quenched specimens causes the return of some troostite.

Fig. 12, contains the microstructure of ingot 445, analyzing 1.20 per cent carbon and 4.62 per cent manganese. As cast, the major portion of the steel is composed of austenite and troostite; fine cementite grain boundaries also are present. A prominent feature, however, is the numerous dark-etching needles to which Guillet applied the name "troosto-sorbite" but which most of the recent writers on this subject have termed "carbides." Annealing gives a structure similar to that found in carbon steels cooled somewhat less slowly from the annealing temperature—cementite boundaries in a matrix of sorbite and some pearlite. After quenching, the steel is almost completely austenitic; there are a few patches of a dark etching constituent, which in the cast metal, at this magnification, are not so readily distinguishable from the closely packed twins of the austenite. Drawing causes a reversion to the sorbitic state, with needles and globules of free cementite; the details of this structure are given in Fig. 17 (a).

With manganese increased to over 8.0 per cent the conditions recorded in Fig. 13 occur. As cast there is found austenite containing cementite, troostite and the "carbide" or "troosto-sorbite" needles and after forging austenite with dark-etching grain boundaries containing an occasional patch of troostite. On annealing troostite and cementite are present in the austenite; quenching of the cast metal from 1650 degrees Fahr. shows them incompletely dissolved in the austenite, although after treating the forged sample in the same manner, they are absent. Strangely enough, this apparently homogeneous austenite does not possess very good tensile properties; also the hardness test does not show any difference between the cast and forged quenched samples. Drawing to 1100 degrees Fahr. produces a rapid increase in hardness and a structure that consists of cementite, troostite and "carbide" needles in a small amount of residual austenite; the details are visible in Fig. 17 (e).

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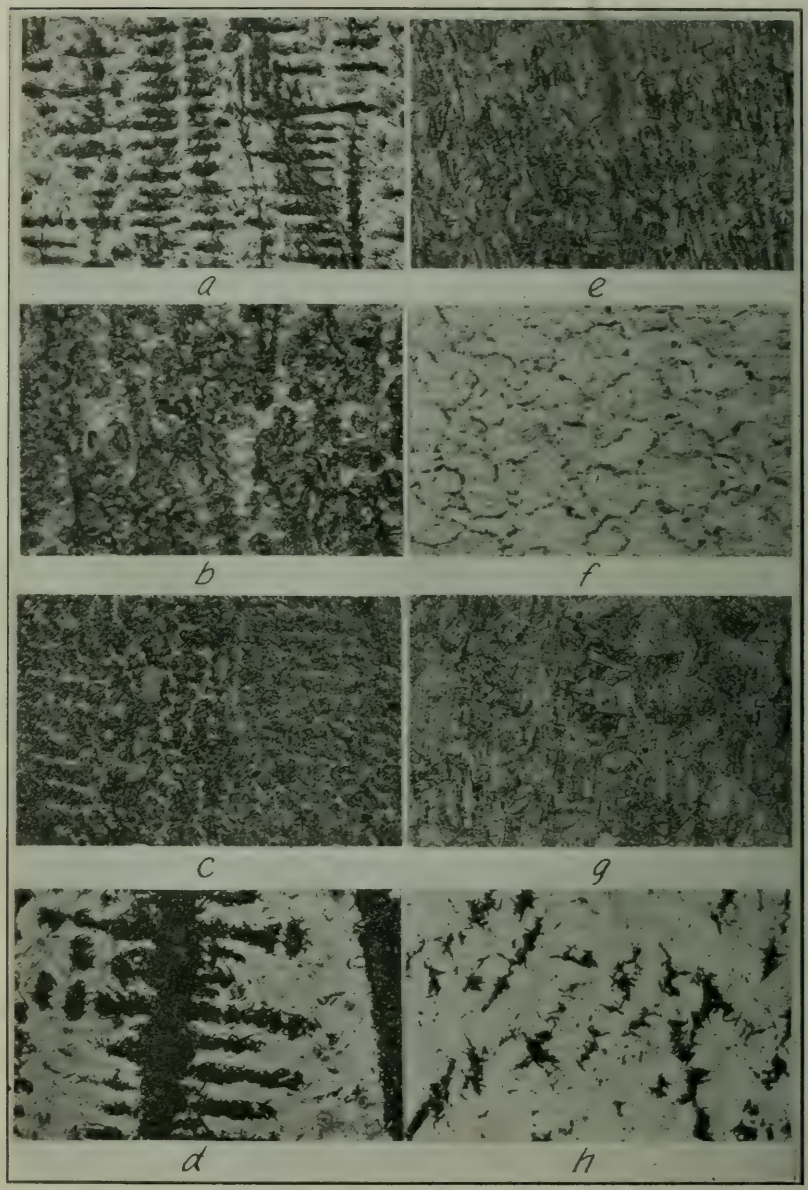

Fig. 6—Carbon, 0.48 per cent; manganese, 8.72 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

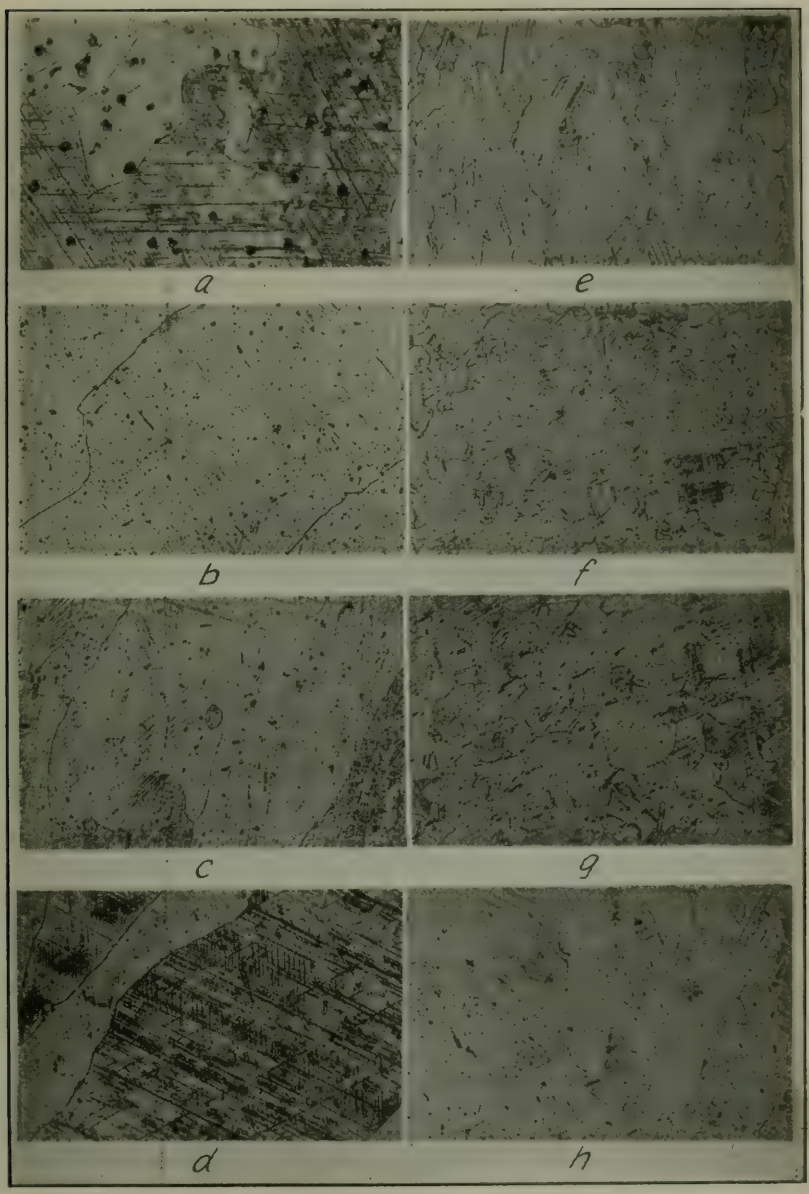

Fig. 7—Carbon, 0.46 per cent; manganese, 14.39 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

When cast or forged, the structure of the 1.25 per cent carbon steel with 12.0 per cent manganese (Fig. 14) is not materially different from the 8.0 per cent alloy. After annealing the metal is still quite similar; the troostite particles are, however, noticeably smaller and the "carbide" needles are quite prominent in both the cast and forged condition. Quenching the cast metal produces a structure very similar to that found with 8.0 per cent manganese, but in the forged specimen leaves appreciable amounts of the dark-etching grain-boundaries unabsorbed. Drawing the quenched samples brings about the structure characteristic of the annealed state.

One alloy was made to study the effect of very high carbon and moderate manganese content but unfortunately the former was higher than desired. In all conditions except the quenched state, the photographs of Fig. 15 show structures of cementite, sorbite and pearlite similar to those of high carbon steels with lower manganese. Quenching produces a fine-grained austenite with intercrystalline masses of cementite which, in the cast metal follow the branches of the dendrites and in the forged alloy are banded in the direction of working. An effort was made to put this cementite into solution by air-cooling from 1980 degrees Fahr. but, as indicated by the tests (and metallographic confirmation) this was not accomplished. Complete solution of cementite for this steel can be had probably only above the liquidus temperature; the properties of very high carbon-low manganese austenite must be studied with a slightly lower carbon content.

Theoretical explanations of the metallography of manganese steels have not been entirely conclusive, particularly those applied to steels of the higher manganese proportions. Although there may be disagreement in the quantitative details, it is generally conceded that for steels under 3.0 per cent manganese, increase in the proportion of manganese causes a lowering of the various thermal critical points and a movement of the loci of these points as represented on the iron-carbon diagram, slightly to the left, thus giving a eutectoid point at a carbon content increasingly lower. Directly related to these facts is the sluggishness, in response to heat treatment, created by additions of manganese.

In general, operation of these same influences is manifested with higher proportions of the element, as translated by Guillet's equilibrium diagram, (Fig. I). This diagram is similar to that for

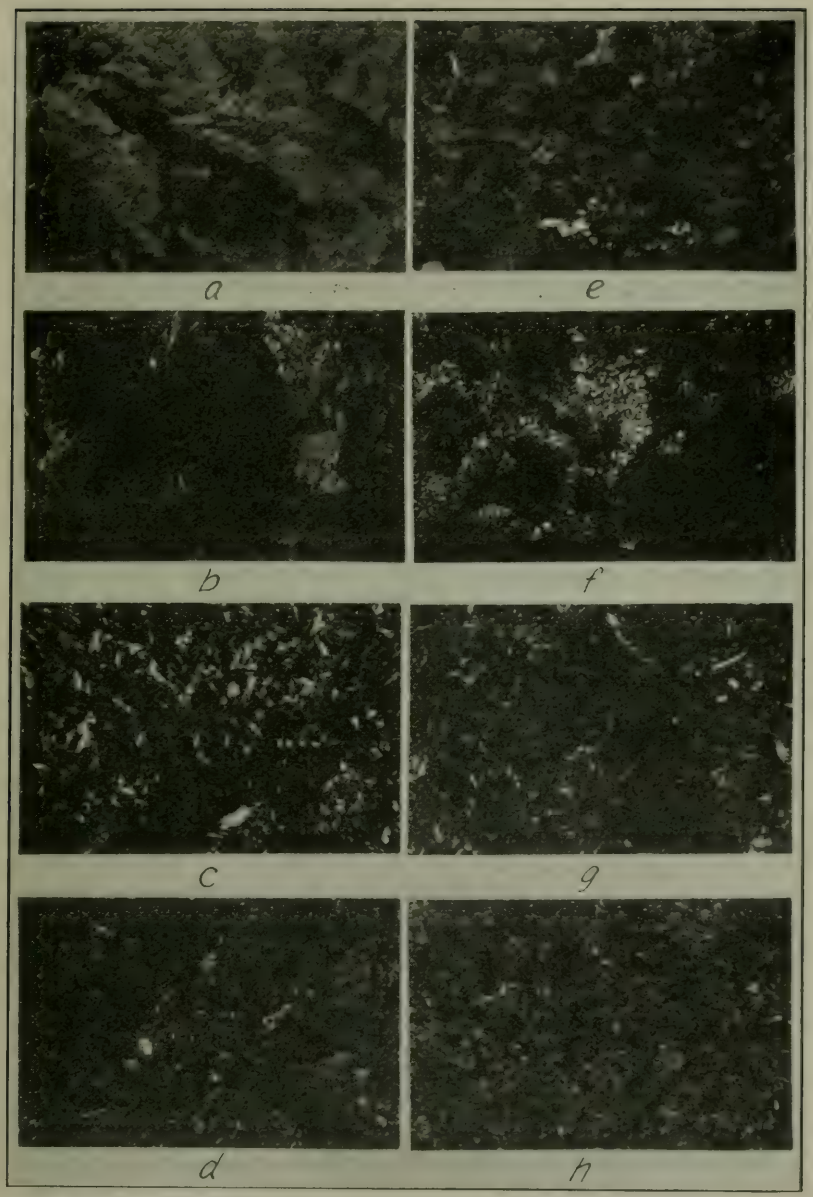

Fig. 8—Carbon, 0.78 per cent.; manganese, 1.86 per cent. All magnifications x 300. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

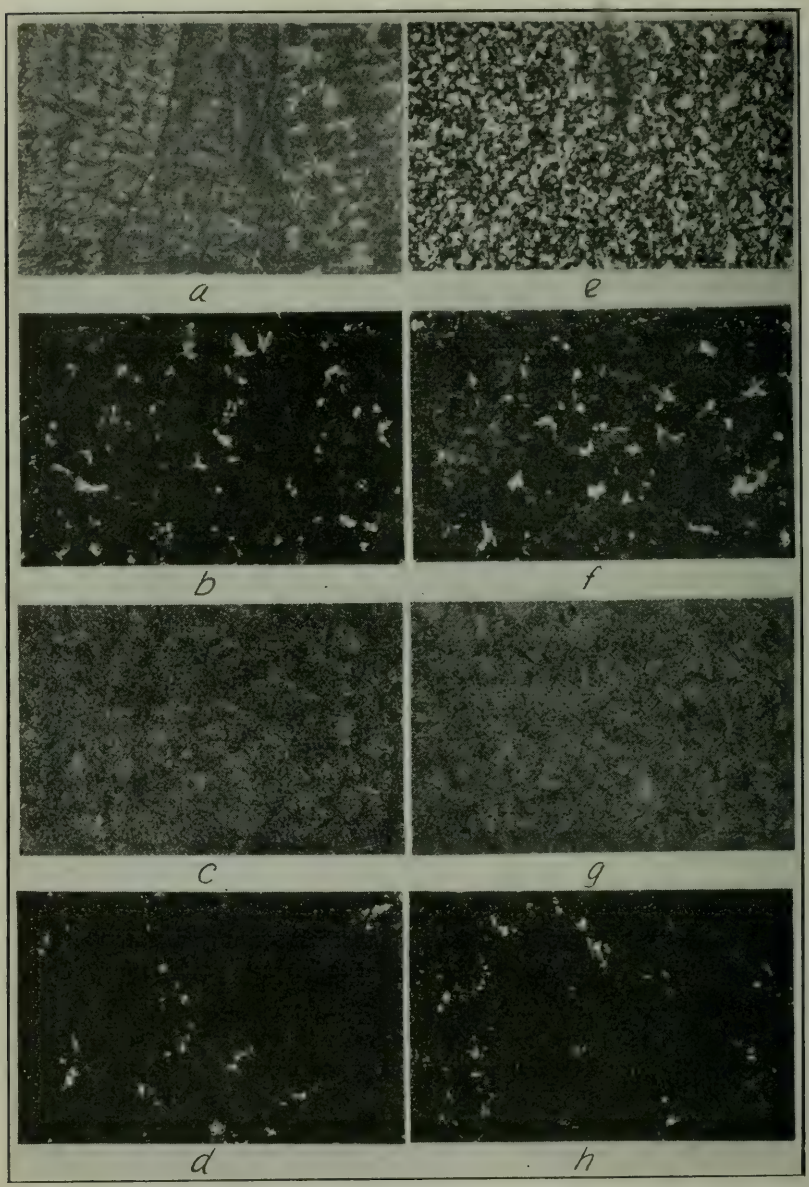

Fig. 9—Carbon, 0.78 per cent; manganese, 4.40 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

nickel steels with the exception that the two areas showing troostite are, in the case of the nickel steels, entirely absent, leaving the entire triangle a martensitic area. In this way Guillet has recorded results which show those differences between the two groups of steels created by the fact that manganese is a carbide-forming element, whereas nickel is not. However, the microstructure of steels high in manganese (and carbon) is not entirely accounted for in this way. Particularly do steels of the austenitic area containing carbon in excess of 1.0 per cent, show structures not accounted for by this diagram. The different stages of decomposition of the austenite of steels of varying carbon and manganese contents, created by both thermal and mechanical causes have received some study but hardly sufficient to furnish a comprehensive theory of their behavior. Such an explanation must account for the presence of the cementite network, the dark-etching hard network, the needles of "carbide" or "troosto-sorbite" and the possibility of martensitic formations. The hardening of "manganese steel" by cold work has been explained by the formation of martensite or cementite precipitated on slip planes; if martensite occurs from this cause, it would seem reasonable to infer that it would also be the first constituent to form in the thermal transformation of the austenite, but this is not by any means certain. Occurrence of the dark etching needles is most common in the steels of higher carbon content, and when it is considered that for a given percentage of manganese, increase of carbon removes the resultant metal more and more from the martensitic and troostitic areas of Fig. I, it does not seem reasonable that all of these acicular particles are of a constituent intermediate between austenite and pearlite. However, if such should be their nature, then in "Hadfield's manganese steel," the thermal transformations are not so much lowered as they are suppressed and data on their location would be of interest. On the other hand, if these needles are carbides, then there must be more than one manganese-iron-carbon compound or mixture of compounds to be accounted for and a comprehensive theory must explain their occurrence and properties. These are but a few of the points necessary to a thorough understanding of these alloys for their magnetic behavior introduces additional complications.

Possibilities of Manganese Steels

It is most difficult in a necessarily restricted space to cover in

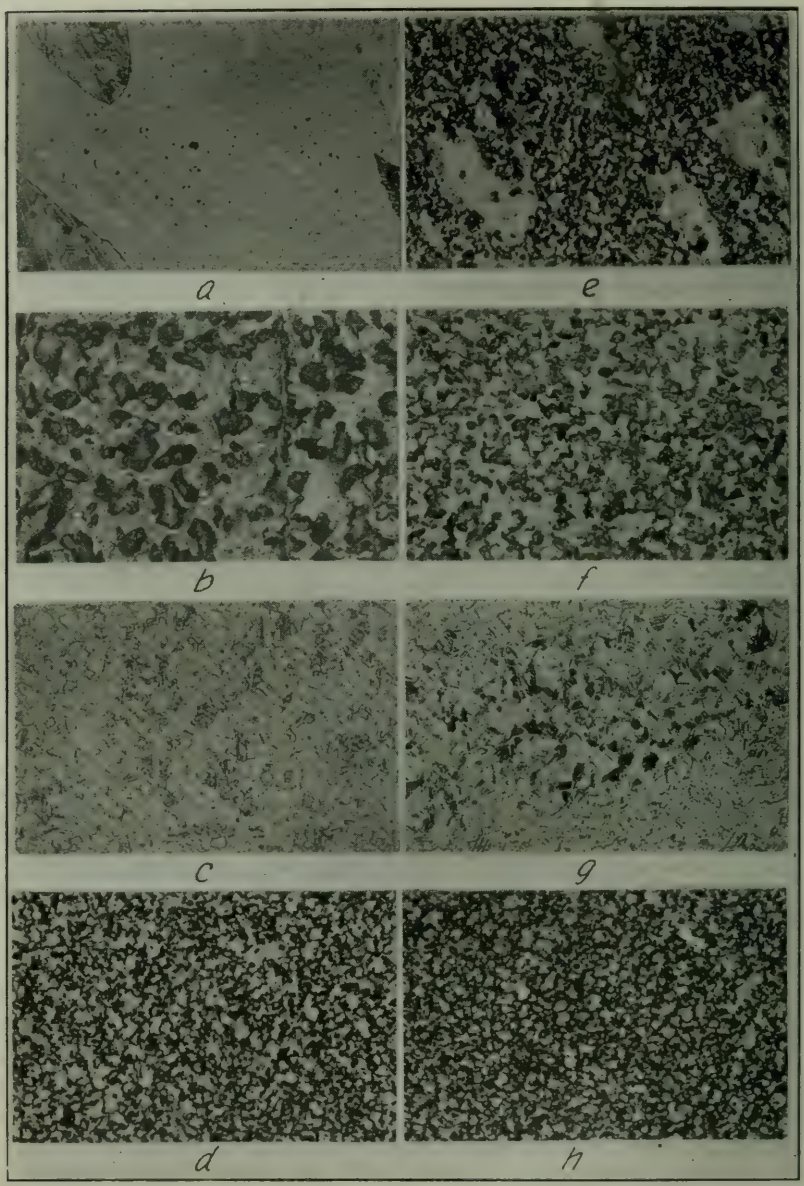

Fig. 10—Carbon, 0.81 per cent; manganese, 8.87 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

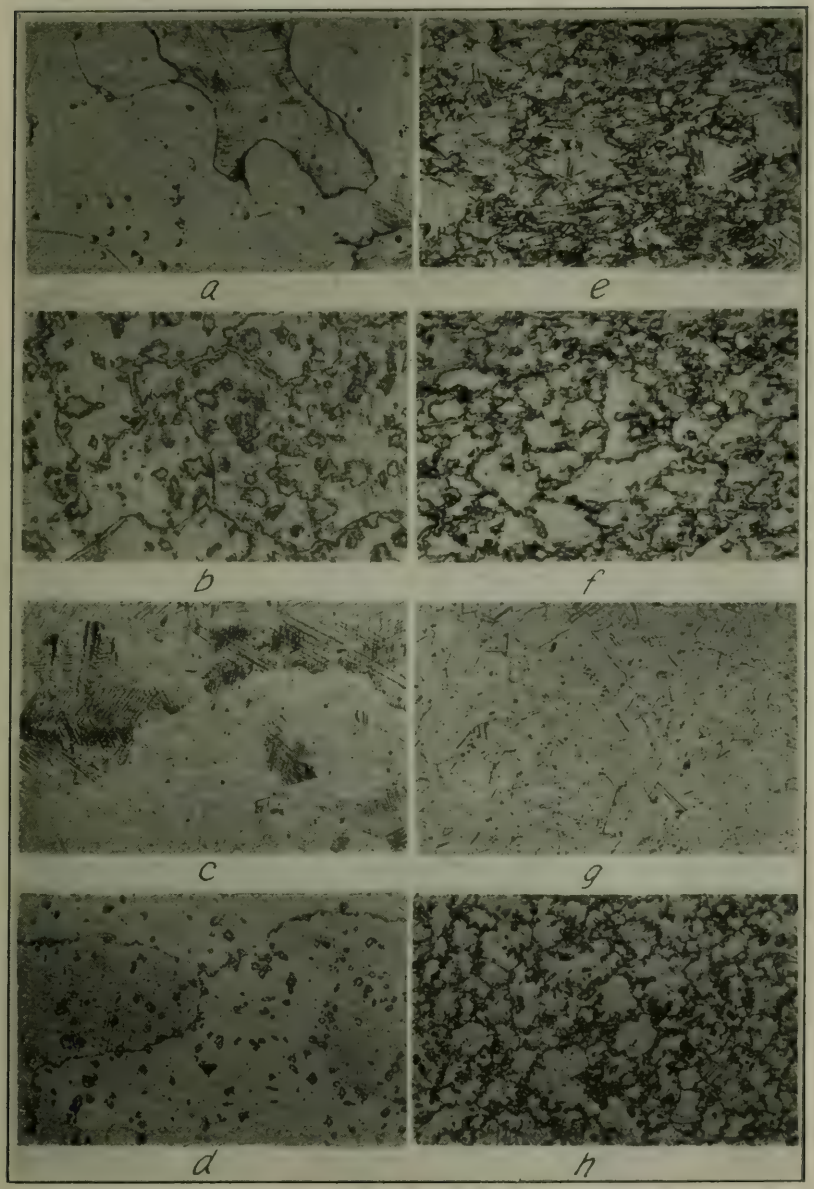

Fig. 11—Carbon, 0.94 per cent; manganese, 12.68 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

detail the entire field of the application of manganese in varying the physical characteristics of steels. Some of the directions for further development and application have, however, been indicated and may well bear repetition or emphasis along with possible uses in more complex systems.

In steels under 0.40 per cent carbon there have been many applications of manganese contents up to about 1.5 per cent. There have also been a few uses of low-manganese steels of similar manganese content but with higher carbon proportions. All of these uses seem fewer than are justified by the circumstances. Here is available a cheap addition agent capable of replacing to advantage certain other alloy additions or, viewed in another light, of providing at small cost an increase in ductility (and related characteristics) by using it in combination with a lowering of the carbon. In some cases, it is even doubtful whether such increase in cost would occur when the decrease in manufacturing losses created by the change in carbon content, is considered. Due perhaps to the widespread association of brittleness with the combination of high carbon and high manganese, specifications for carburizing steels have limited the presence of the latter element to 0.60 per cent or less. It is most probable that research in the direction of low-carbon steels with up to 2.0 per cent manganese, may show the above limit to be most arbitrary and may further indicate combinations that for some purposes could replace other alloy steels now in use. The characteristics of quaternary combinations including 1.0 to 2.0 per cent manganese require further investigation and the study of such steels containing vanadium, molybdenum, chromium, copper, etc., may develop structural materials of much value. In this connection the use by the Naval Gun Factory of a casting and forging steel containing 0.30 per cent carbon, 1.0 per cent manganese, 1.5 per cent nickel and 0.4 per cent copper, is of interest.

The high-manganese steels also seem deserving of additional research. The study of the relations between chemical composition, melting and casting practice, mechanical treatment and thermal treatment, as combining to produce the characteristics of the ultimate product have not yet brought perfection. Troostite, cementitic and also "carbide" masses, network and needles have often been causes of failure; the microstructure of failed parts varies widely as to

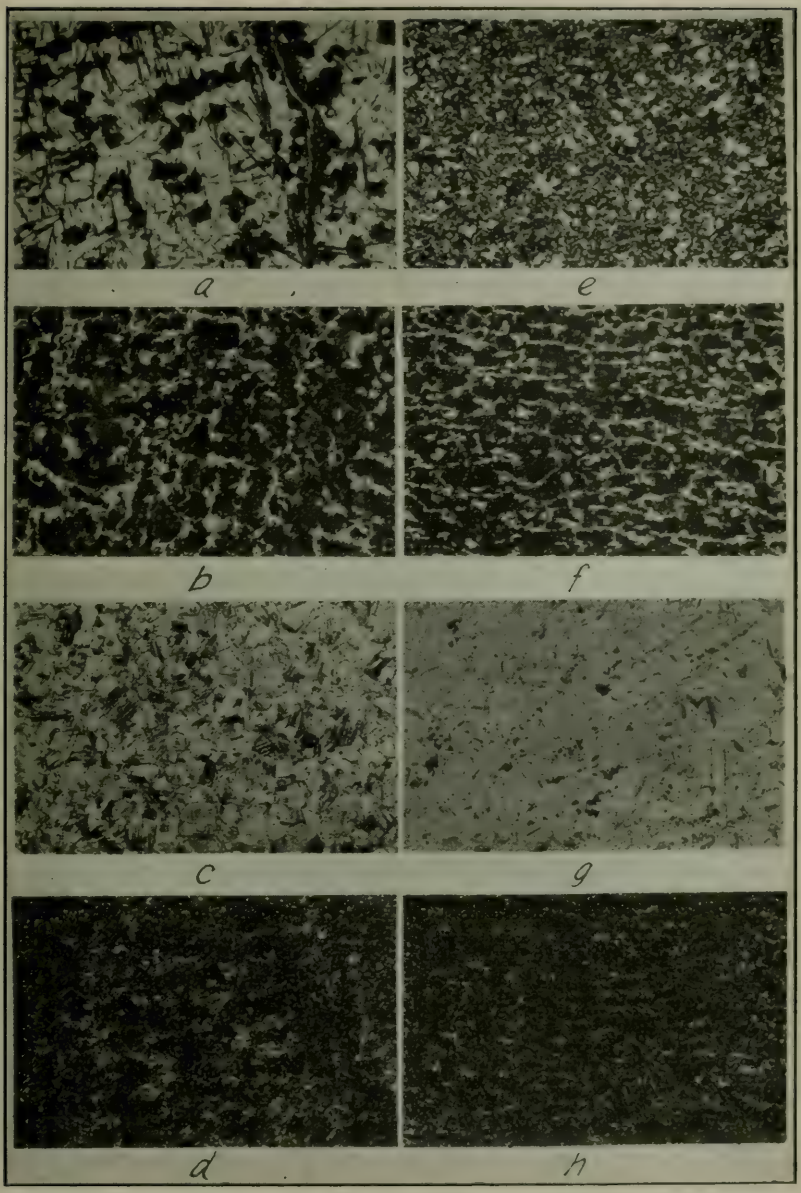

Fig. 12—Carbon, 1.20 per cent; manganese, 4.62 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

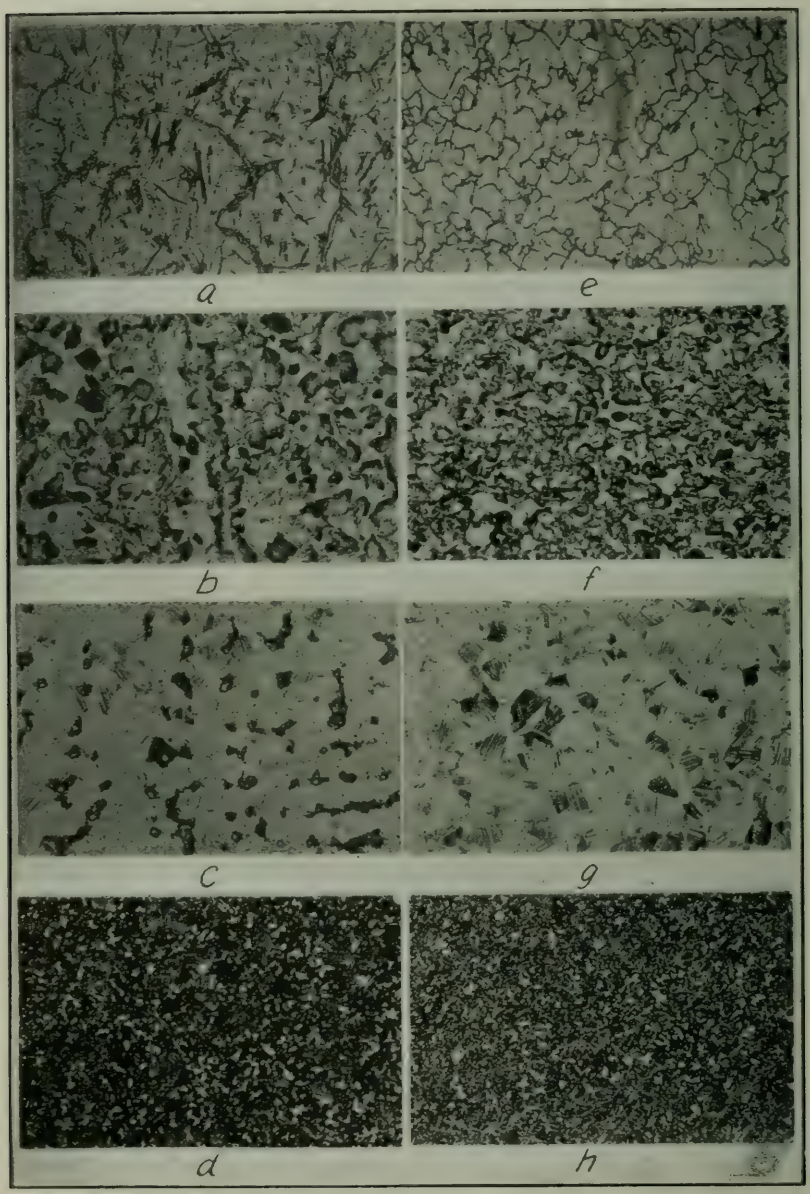

Fig. 13—Carbon, 1.27 per cent; manganese, 8.68 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

the presence or absence of the above constituents; the cause or causes of the occurrence of each has not received sufficient attention. Naturally any modification that will help to curtail the number of failures by removing the causes, without simultaneously reducing those properties upon which serviceability depends, will be a step forward. The nature of the hard constituents usually responsible for failures and their mode of occurrence cannot be entirely explained from these few tests but certain facts stand forth prominently and help point a way. The alloys coming within the scope of the term "Hadfield's manganese steels" are covered in Figs. 10, 11, 13 and 14. It will be observed that the needles of "carbide" occur only in the higher carbon steels, that the production of a 100 per cent austenitic structure (hard constituents absent) is readily accomplished at a low temperature in the low-carbon steels, but not so readily in the higher carbon steels; also for a given manganese content, decomposition of the austenite into hard constituents on reheating, is greater in amount in the steels with higher carbon. This difficulty of complete solution of the "carbides" at low quenching temperature is clearly brought out in Fig. 16; as in the previous instances the formation of 100 per cent austenite is more difficult in the cast state. Fig. 16(g) is a clear exposition of the situation; this photograph shows at low magnification the edge of the bar illustrated in 16(e); analysis of a cross-section of the bar, excluding the surface, gave a value of 1.25 per cent carbon, but at the edge there was found only 0.96 per cent. Of course, austenitic structures can be obtained if the quenching temperature is sufficiently high but such increase, aside from the added cost of fuel and furnace upkeep, produces an enlarged grain (Fig. 17) and greater quenching stresses that ultimately mean inferior mechanical properties (Table V). These considerations naturally apply to castings more forcefully than to rolled or forged bars; they are also more applicable to thick than to thin sections. Because of such conditions the author favors the use of a slightly lower carbon content than is the custom of many producers. In some cases this can be accomplished with existing materials and processes; in others it must await the development of low-priced manganese alloys containing less carbon than those now manufactured. The effect of such a change of composition on

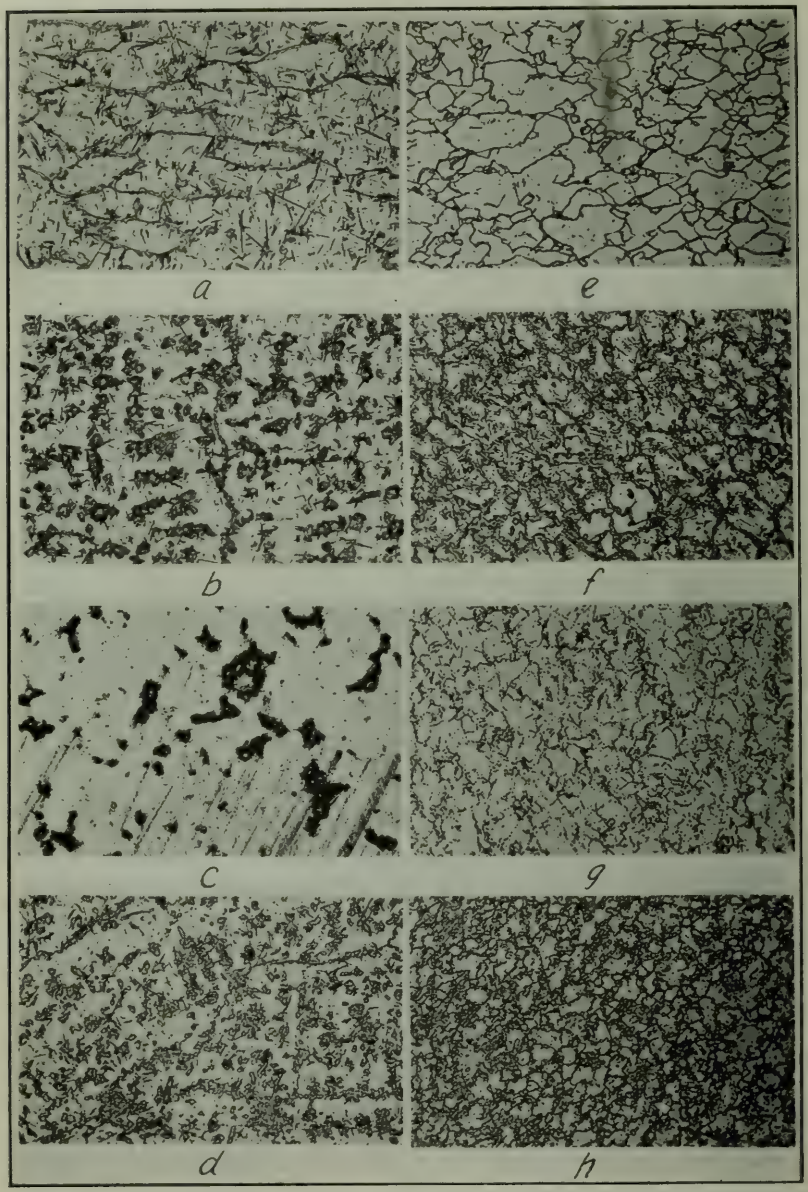

Fig. 14—Carbon, 1.22 per cent; manganese, 12.40 per cent. All magnifications x 100. (a), (b), (c), (d) cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

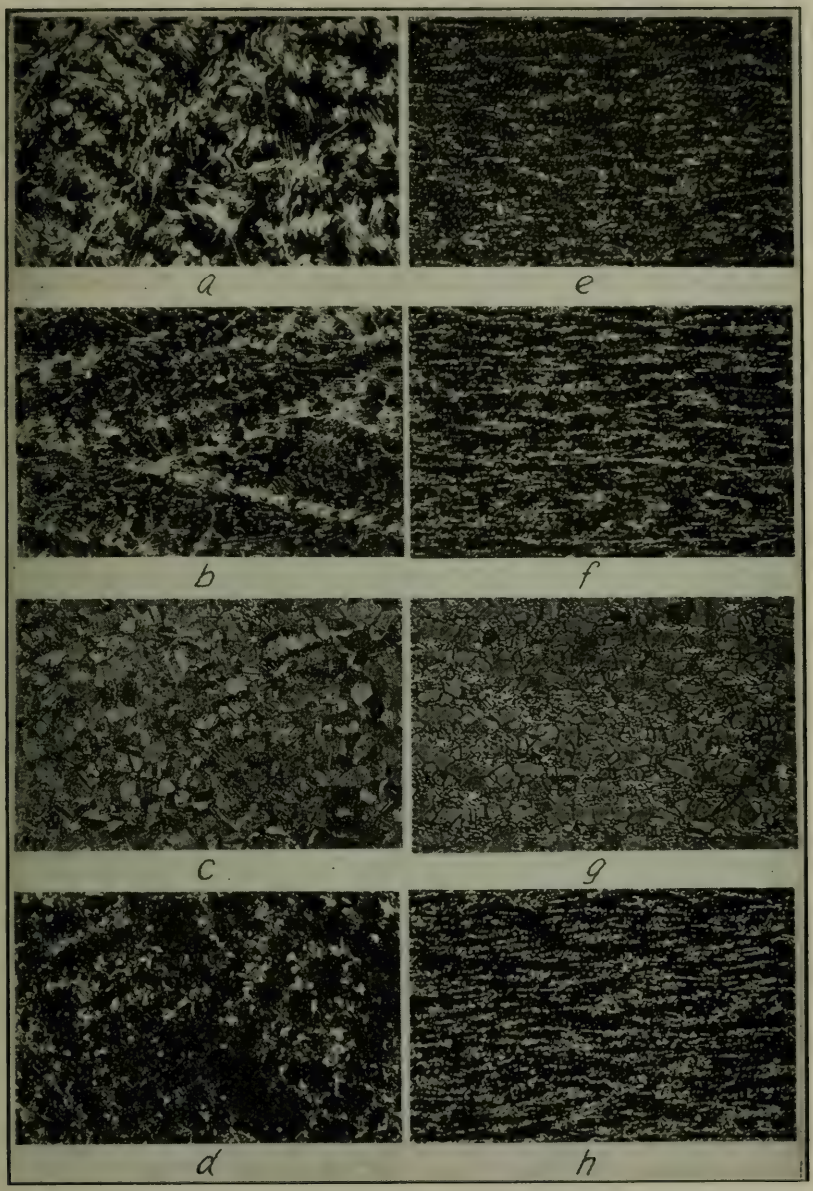

Fig. 15—Carbon, 1.85 per cent; manganese, 4.26 per cent. All magnifications x 100. (a), (b), (c), (d), cast; (e), (f), (g), (h) forged. (a) as cast; (e) as forged; (b) and (f) 1600 degrees Fahr. (15 min.) furnace cooled; (c) and (g) 1650 degrees Fahr. (15 min.) water quenched; (d) and (h) 1650 degrees Fahr. (15 min.) water cooled, 1100 degrees Fahr. (30 min.) cooled in air.

the tensile properties is slight and probably in favor of the lower carbon combination. Using for each steel the minimum quenching temperature required to obtain complete austenitization, it is doubtful whether any appreciable difference in proportional limit would result, whereas it is reasonably certain that there would be a gain in impact resistance with the finer grain resulting from the lower quenching temperature. In favor of this lower quenching temperature made possible by the decrease in carbon is the present quenching practice for many rolled products, which involves water

Table IX

Tensile Properties of Manganese Steel

Carbon Content—1.25 *per cent*
Manganese Content—7.62 *per cent*

Bar No.	Condition	Heat Treatment	Prop. Limit lbs. sq. in.	Tensile Strength lbs. sq. in.	Elongation in 2" per cent	Reduction of Area per cent	Fracture	Brinell
X-103	Cast	1650°F Water	55000	85500	3.8	5.9	Ang. Gran.	251
X-102	Cast	1800°F Water	49500	75800	7.3	11.3	Ang. Gran.	192
X-101	Cast	2000°F Water	46800	77400	16.0	22.2	Ang. Gran.	...
X-107	Forged	1650°F Water	55000	105400	11.3	13.9	*Sq. Gran.	217
X-106	Forged	1800 F Water	46800	102800	25.5	29.1	*Sq. Gran.	187
X-105	Forged	2000°F Water	45800	100300	25.8	31.1	*Sq. Gran.	...

* Broke in points.

cooling immediately following rolling and without reheating. Here slight delays mean "carbide" precipitation and a resultant product not in its best possible condition for impact resistance. Referring to Table VII, a higher quenching temperature to avoid the hard constituents in test bar X-33 would have slightly lowered the proportional limit and increased the elongation, but the resultant bar would still be inferior to X-21. In connection with these tensile tests it must be remembered that better results than X-33 or its modification by a higher quenching temperature as indicated, are obtainable in practice because the present test bars were made by a 10 to 1 reduction from the ingot whereas usual practice for rails is about 40 to 1 and for bars often 300 to 1 or more. The figures of Table IX support the statements relative to the effect of complete solution of hard constituents and also the effect of working; the forged bars were produced by a reduction of 60 to 1 and should be compared as to tensile properties with specimen X-15 (Table VII).

There remains for consideration only the use of manganese in large percentages along with other alloying elements as a constituent

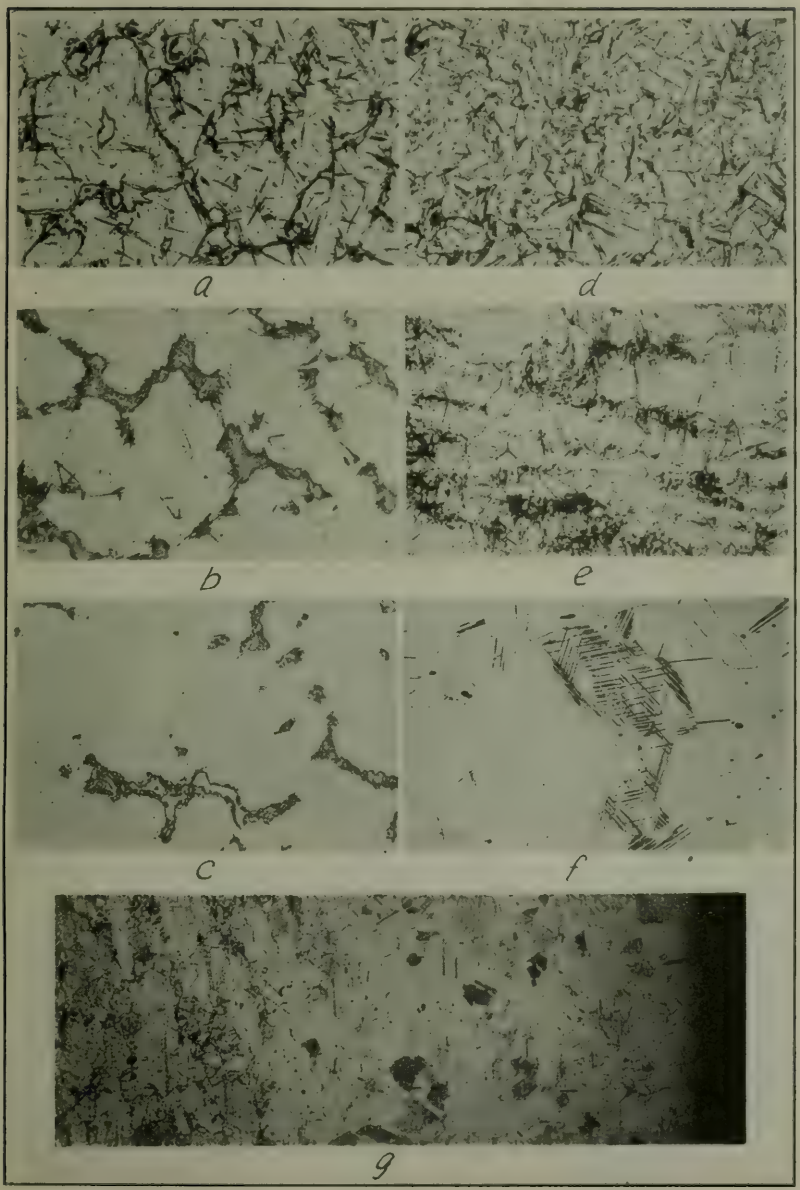

Fig. 16—Carbon, 1.25 per cent; manganese, 7.62 per cent. Magnifications (except g) x 100. (a), (b), (c), cast; (d), (e), (f), (g) forged. (a) as cast; (d) as forged, (b) and (e) 1650 degrees Fahr. (15 min.) water quenched; (c) and (f) 1800 degrees Fahr. (15 min.) water quenched; (g) same as (e) showing surface of bar, magnification x 40.

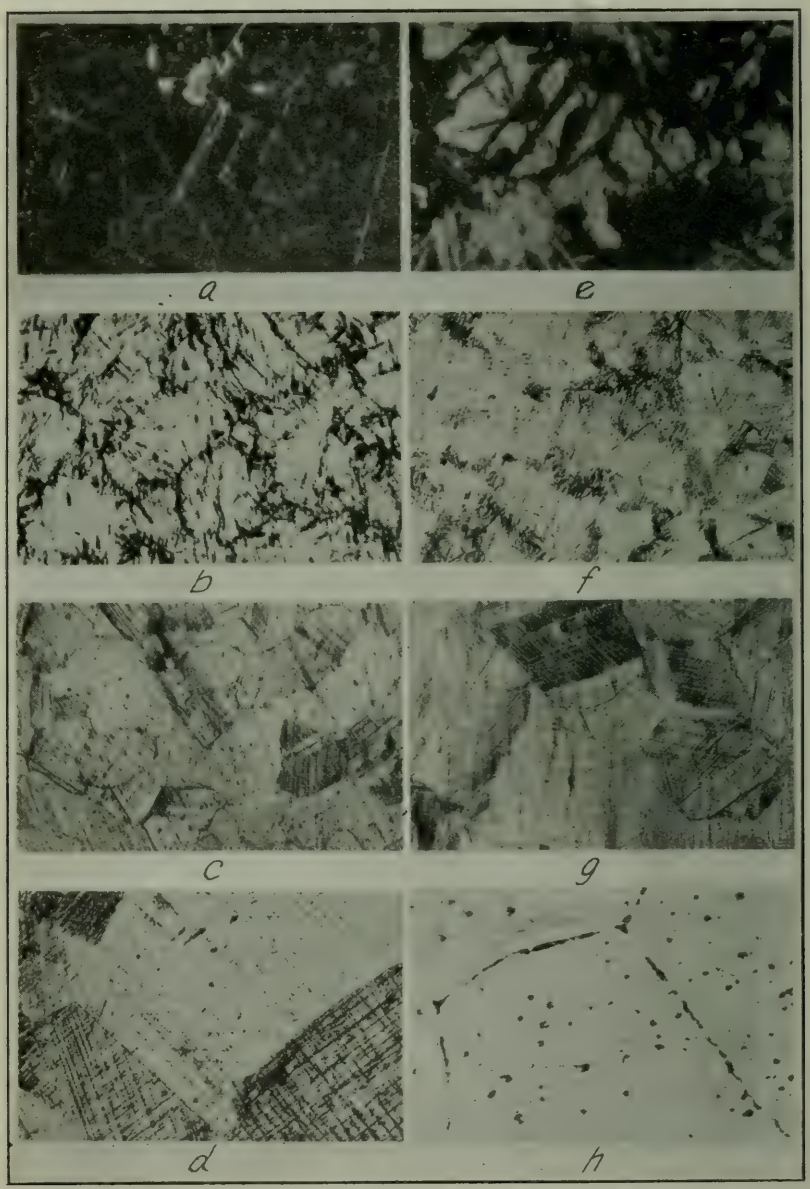

Fig. 17—(a), same as 12 (d) x 800; (e), same as 13 (d) x 800. (b), (c), (d) (f), (g), (h), rail steel, carbon, 1.10 per cent; manganese, 11.42 per cent; (b) 1290 degrees Fahr. water quenched; (f) 1560 degrees Fahr. water quenched; (c) 1650 degrees Fahr. water quenched; (g) 1920 degrees Fahr. water quenched; (d) 2190 degrees Fahr. water quenched; (h) 2370 degrees Fahr. water quenched.

of austenitic steels. Improvement of the wear-resisting Hadfield steels has been attempted and in this direction the introduction of chromium has been successful in raising the proportional limit although at the expense of considerable ductility. However, the use of this combination has not been extensive. Addition of other elements such as nickel, copper and vanadium has been mentioned but no data as to their effects have been made available. The foremost objection to such composition modification appears to be the increased cost, and this objection will not readily be overcome unless extreme improvements are demonstrated.

Within the past few years there has been a rapidly increasing use of austenitic nickel steels containing chromium as a hardening element. They have been advanced as structural steels for applications where resistance to corrosion was a vital factor and have withstood successfully many corrosive influences; in most instances they represent a considerable improvement over the 25.0 and 35.0 per cent nickel steels. During the late war, however, Germany keenly felt her shortage of nickel and undoubtedly because of this, was led to modify these nickel steels by partial substitution of manganese, even though the latter was none too plentiful. The following analyses were made on samples taken from three German submarine periscope tubes acquired during the war period:

No.	C	Mn	Ni	Cr
1	.54	.60	23.67	1.18
2	.73	5.07	16.56	None
3	.71	6.68	11.62	4.17

The first is a nickel steel with a small amount of chromium similar, except for slightly lower manganese and nickel percentages, to an early type of chromium-bearing high-nickel steel produced in this country. Metallographically, the second is approximately equivalent to a 27.0 per cent nickel steel and the third to 25.0 per cent nickel steel with the same chromium content. It is steels similar in composition to the third one in this list that were referred to as having recently been so widely applied, the usual types, however, containing less than 0.50 per cent carbon and as high as 18.0 per cent chromium.

The use, of course, of these austenitic manganese-nickel

steels is not an innovation [15] [16], but is worthy of close attention for although the corrosion-resistance of these steels may be considered low in comparison with austenitic nickel and nickel-chromium alloys, the fact remains that these tubes were functioning well and showed no corrosive effects other than the very thinnest film of oxide. It is always well to heed such occurrences as this, because in the last analysis, it is a combination of cost and ability to meet service requirements that means success or failure.

The author is indebted to Louis Jordan of the United States Bureau of Standards for the preparation of the small ingots and desires also to acknowledge the assistance of Harry Schultz in the metallographic work and J. W. Talley in carrying out the heat treatments.

15. Carpenter, Hadfield and Longmuir—Seventh Report of the Alloys Research Committee, Institution of Mechanical Engineers, 1905.

16. Guillet—Quartenary Steels, *Journal* of the Iron and Steel Institute, 1906.

SOME OBSERVATIONS ON FURNACES AND FUELS INCLUDING THE ELECTRIC FURNACE FOR HEAT TREATING

By E. F. Collins

Abstract

This paper points out the undeniable fact that furnace selection, whether fuel or electric, has been in the past one largely influenced by the promoter rather than the engineer. It is urged that executives avail themselves of the service of the furnace engineer in the future, and it is urged that these engineers make selections after a complete study of the requirements, giving due consideration to the various factors involved and their relative importance. Furnaces should be fitted to processes rather than attempt to fit special processes to standard furnaces.

Attention is briefly called to the adaptability of the electric heat treating furnace of the metallic resistor type for carbon steel heat treatment.

Assuming that proper selection of furnace and fuel has been made, it is urged that intelligent and capable handling and management be added, in order to secure the lowest "over all" costs for the manufactured product.

Finally, if the electric furnace is used, where careful analysis of conditions call for it, substantial "over all" economies are returned.

Industrial Heating a Broad Field

HAVE you ever noted how heat, in one way or another, influences quality, cost, and the utility of practically every manufactured article? Especially is its application far-reaching in the manufacture of metal and its fabrication. Yet it must be confessed that industrial heating in the past has not had the attention of the high-grade engineer, as its importance deserved. All too often the selection of equipment has been left to those who were ruled more strong-

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A paper presented at the annual convention of the society, Pittsburgh, October 8-12, 1923. The author, E. F. Collins, is consulting engineer, industrial heating division of the General Electric Co., Schenectady, N. Y.

ly by the promoter, than by the scientific analysis of the requirements. Many essentials such as fuel values, method and efficiency of heat conversion, temperature controls and pyrometers, should receive their full share of technical consideration.

Danger of Wrong Deductions

Many wrong deductions regarding the efficiency of electric heat versus fuel heat, come from comparing an inefficient electric furnace, perhaps improperly operated, and in design not suited to the specific process and manufacturing conditions, with a fuel-fired furnace which is suited to the fuel and the process, and is more efficiently operated. The difference in economy resulting is too often charged to the difference between electric heating and fuel heating. In this connection, the writer recalls an example of such an erroneous deduction. A piece of heating equipment improperly designed for the economical application of electric heat was, nevertheless, fitted with electric heaters. It turned out a product with a consumption of about one kilowatt-hour for 3.5 pounds when electrically heated. This same piece of apparatus was almost ideally suited for fuel heating, and when operated with oil heating, gave a cost for treating the product of only one-ninth of the cost with electricity.

Proper design and proper operation of apparatus for the same work, when electrically heated, gave 35 pounds per kilowatt-hour (or 10 times 3.5). The reason then for doing work at one-ninth the cost in the fuel-fired equipment was that the design was suited to oil heating and unsuited to electric. It would not have been reported that electric heat was nine times more expensive than oil for the same purpose, if those making the comparison had not been mistaken as to the cause of the difference. They erroneously charged it to the use of different "fuels" rather than to wrong designs, which defeated the proper application of electric heat.

Design Should Fit the Fuel and Work

In order to forestall charges of misapplication of a "fuel" designs must take advantage of the inherent characteristics of electricity or a fuel, as the case may be. Again, furnaces of the box type, used by intermittent charging, should not be

compared to "tunnel" type or continuous conveyor type, neither should "noncompensated" or "nonregenerative" furnaces be compared to compensated or regenerative types with the expectation of equal performance. In such cases we should look for a more or less wide variation in performance between the different types when used under the same conditions. The lowest "over all" cost of production will usually demand one particular type furnace, depending upon the requirements of the product.

Relation Between B. t. u. Cost and "Over All" Cost

There is no direct constant relation between the calorific value of a heat source and the "over all" cost, in industrial heating. The "over all" cost is a function of (1) the character of the "heating cycle" required by the product under manufacture, (2) the equipment provided for the application of heat, (3) the conditions under which the equipment is operated, (4) the efficiency of operators, and (5) the cost of the heating medium, be it electricity or fuel. All these factors combined determine the factory costs, using fuel or electricity. The quantity consumed affects the cost of production usually to a lesser degree than any other single factor listed above. Fuel consumption, for a given process, may easily be twice as great in one furnace as in another doing the same work but having a more efficient design. Again, it is true that a well designed equipment may be so inefficiently operated, (especially in fuel furnaces) that it consumes double or treble the quantity of heating fuels or electricity that a watchful and highly efficient operator would use for the same production with correct methods of operation.

Conditions for Minimum Fuel Cost

Few manufacturers can control the price paid for their fuel directly. A manufacturer can, however, just as surely keep his cost of fuel to the minimum, by using furnaces and heating equipment designed to suit his processes and the conditions in his own plant. He should use heating apparatus designed not only to produce heat but which does apply and utilize it with the greatest efficiency in each individual proc-

ess. In other words, he should fit his heating equipment to the process and not attempt to fit his process to the equipment.

Another feature which enters into the selection of a particular fuel or electricity, and which is many times of greater economic value for a heating process than the B.t.u. content of the "fuel" or the perfect release of the heat content; is what has been termed "form value."

Were it not for the "form value," and if the B.t.u. content of the fuel were the whole criterion, then the use of oil or manufactured gas could hardly prove economical in the face of the low cost of bituminous coal, from the standpoint of its B.t.u. content. It must be admitted that this "form value" is somewhat intangible, but in the "over all" cost of production it appears as a very real element.

"Form value" results from physical condition or chemical combinations in a heat energy source, entirely separate and apart from B.t.u. content, such that an advantage comes about in the application of its heat to useful service. Here the price of fuel or electricity, type of furnace, and the heat balance for the process, are excluded from the commonly accepted conception of "form value."

Selecting the Proper Furnace

Hence when the furnace engineer surveys a given process, and considers various fuels or electricity as the source of heat, he should not neglect to give due consideration to "form factor"; a very real factor influencing "over all" costs. This is equally as important and many times more so than such factors as price of fuel or electricity or B.t.u. heat content, heat balance for the process, or the first cost of the heating apparatus.

It is desired to emphasize the absolute necessity for the furnace engineer to make a detailed study and survey covering in detail the foregoing general factors vital to a correct design for heating equipment which will produce the most efficient results. Whether the heating shall be done with fuel or electricity can only be determined from such study. If electricity is selected, then should heat be generated by re-

sistance, by induction, or by the arc? If fuel is to be used, then what form of fuel will give the lowest "over all" cost?

We are accustomed to make careful and exhaustive study of the application of the electric motor in the power field, and of the electric light in the field of illumination, and so must we make the same critical and unbiased study of the best methods of applying electric heat to industrial processes. It is a fact that while the cost of electric heat enters only indirectly into the "over all" cost of production, it enters as a greater factor usually than electric energy does in the motor and lighting fields, therefore, we can afford to use no less exact engineering methods in applying electric heat to industrial heating processes. If fuel heat is to retain its portion of the heating field rightfully belonging to it, then engineers must give the same careful attention to the application of the proper fuel in equipment correctly designed. Much fuel burning equipment is met with today which shows that proper analysis of the application of heat has not been made. Had this been done, many fuel-fired devices that are now in use, would already have been discarded for the electric; while others would have been redesigned to give the most that fuel firing has to offer.

Many Fuel-Fired Furnaces Operate Inefficiently

As illustration of the latter statement, we note in a prominent furnace engineer's bulletin the following illustrations of economy affected by proper selection and design of fuel furnaces to meet heating requirements and plant conditions.

Process	Increase of Output Per Unit Floor Space Per Cent	Unit of Fuel Per Cent
Small drop forge (a)	37	78
Small drop forge (b)	275	27
Small drop forge (c)	250	47
Large drop forge		90
Heat treating steel	17	33
Hardening steel parts	50	
Annealing steel	103	25
Carburizing		90

This list is sufficient to indicate that industrial heating processes should receive the attention of the trained furnace

engineer, and when such practice is followed, is bound to result in much economy. We are apt to be concerned over a matter of one or two per cent in the efficiency of a motor and yet the foregoing table reveals the improvement all the way from 25 to 275 per cent may be secured, not infrequently, by competent furnace engineering. Were we given the opportunity to study conditions existing in the heat treating, hardening, annealing and carbonizing furnaces in this table, giving due consideration to the advantages of the electric furnace, we would, no doubt, conclude that these furnaces would give a still higher "over all" efficiency if electrically heated. This is not mere conjecture, but the result of experience in using the electric heat for these processes. Where quality enters as an important factor, and the usual rates for electric power prevail, it seldom happens that fuel will show lower "over all" cost of manufacture, nor the same great uniformity and high physical characteristics for the heat treated product.

The B. t. u. Cost Factor May Disappear

Exceptional cases exist as illustrated by the hot air pumping engine, in an isolated rural district, and which is very much less efficient than the present day gas engine or oil engine as regards its thermal efficiency or consumption of fuel. Yet it has peculiar advantages such as use of cheap fuel, little need of attention and a resultant "over all" economic value which more than offsets its high consumption of heat B.t.u. for the work done. This is but another illustration of how the quality of B.t.u. consumed and its cost may be completely obliterated by other more important considerations.

We may agree, then, that the B.t.u. value is only one element of the economic value of a fuel for industrial heating when the "over all" cost of manufacture is the controlling consideration, as it should be. Fuel and electric heat each have their fields of usefulness, where one cannot compete with the other; also fields where there is little to commend the use of one as against the other. It would seem that the true furnace engineer should follow the broad law of conservation and urge the use of that type of heat which will conserve our energy supply.

Efficiency of Fuel Burning

Coal, oil, gas and water power are the principal present day sources of energy in the country. This group furnishes energy required by modern conditions. It is estimated that about one-third of this energy is devoted to the production of heat and light, or in other words, something like 150,000,000 tons of coal is used for metallurgical processes. This fuel is used with an average efficiency the country over of about 10 per cent in metallurgical furnaces. An average of 250 miscellaneous oil burning furnaces gave, actually, a thermal efficiency of 9.2 per cent.

It may be interesting to note that if a good steam-electric plant delivers 12 per cent of the fuel at the bus, and if a super steam-electric plant delivers 19 per cent of the fuel B.t.u. at the bus, then an electric furnace with a thermal efficiency of 80 per cent will in the first case utilize 9.6 per cent of the fuel in useful work, while in the second case it will at the same efficiency deliver 15.2 per cent of the energy of coal burned under the boiler to the charge to be heated. Since the cost of burning coal is less per ton in the central station than in the average fuel furnace for metallurgical purposes, it is evident that electric heat often conserves the coal supply and often may compete with fuel processes without any serious handicap from the B.t.u. cost factor. In some cases where water power is sufficiently available, the lower cost may be on the side of the electrically generated B.t.u.

Electric Heat and Steel Making

Little is definitely known as to details of heating methods used for making the first steel. Authorities in such matters tell us that the melting was done in a crude Catalan forge, which consisted of a bowl formed by the side of a hill and wall. The blast was probably generated through the medium of a clay tube and some skins forming a primitive bellows. The fuel was probably charcoal, and it was mixed with the iron ore and placed in the bowl of the forge. The affinity of the iron for carbon gave a resultant fused mass containing a small per cent of absorbed carbon, making it harder and better for tools.

Aristotle in 250 B. C. describes steel making of that period thus: Iron was first smelted from its ore in Catalan forge, giving

a mass of sponge iron full of slag and cinders in the bottom of the bowl. This sponge was hammered to relieve it so far as practicable of cinders and undesirable material; then broken into small pieces and again melted in a small clay crucible together with small wood chips and green leaves, from which resulted a very fine smooth steel which would take a remarkable fine temper.

We do not know the history of the discovery of tempering this steel, but it was probably accidentally accomplished when a piece of the red hot metal was thrown or plunged in water to cool it more rapidly.

Damascus steel is said to have been a crucible steel and has a peculiarly streaked appearance and nothing has, to date, exceeded it in taking a fine temper. It is not superior, however, over steels of later periods as regards metal cutting.

Huntsman produced the first modern crucible steel in the eighteenth century, and Mushet early in the nineteenth century further perfected the crucible method; then came the modern open hearth, followed by the Bessemer process. Hence for thousands of years, there occurred practically no fundamental changes in methods of steel making. The stupendous advance of the past 50 years in steel making has been associated with the open hearth, and Bessemer process, not to mention the crucible process for high-quality alloy steels. However, perhaps, the most wonderful progress of all has been made in the past decade in uniformity and definite composition and physical characteristics of superquality steel through the intelligent use of the electric melting furnace in the hands of trained metallurgists.

Steel Melting Furnaces

The first steel melting furnace was developed by Siemans in 1882; extensive development was slow until 1915 when records show 213 electric melting furnaces in the world, while in 1920 it is estimated there were a total of 1390 or an increase of 650 per cent in five years.

Electric Heat-Treating Furnaces

It is being rapidly and conclusively demonstrated that electric heat will offer advantages equal to or greater in reheating and general heat treatment of steel, than it has done in melting

and refining. A striking expansion in the use of the electric resistance furnace for the heat treatment of steel is shown in the past five years and progress in the demands of industry is sure, henceforth, to require the "over all" economy and high quality which accompany the use of electric heating for such processes, as, (1) annealing, (2) carburizing, (3) hardening, (4) and tempering or drawing of steels.

It is being daily demonstrated that the electric furnace for reheating, when properly designed and used on steels having uniform characteristics such as may be had from the electric melting furnace, can show an advance in uniformity and quality over the usual steel product of the present day fuel-fired furnace. Furthermore, furnaces are available for any and all tonnage requirements and of such simple and dependable design that their continuity of operation equals that of any fuel-fired furnace, while the low upkeep cost usually is on the side of the electric furnace. To this may be added automatic control of temperatures, duplication of heating cycles, reduction in defective heat-treated parts and usually many other influencing factors which work in the direction of a reduced "over all" cost of production in favor of the electric heat-treating furnace.

The Metallic Resistor Furnace

Important heat-treating processes, in which the metallurgist should be interested, and for which the metallic resistor electric furnace is peculiarly adapted, will be enumerated and briefly described so that the working field for such type of furnace may be clearly indicated. We may, for convenience, consider electric heat-treating furnaces under two heads, viz., (1) those used in production of dies and metal-cutting tools and (2) those employed in the heat treatment of machined, rolled or forged parts.

The production of dies involves the following heat-treating processes: (1) annealing, (2) carburizing, (3) hardening, (4) drawing.

In hardening drop forge die blocks, it is claimed much trouble is obviated by annealing the blocks before performing machine operations on it. Bringing blocks up to the proper annealing temperature at a rate of perhaps 45 minutes for each inch of

thickness, followed by cooling in the furnace, insures against trouble such as warping, checking, cracking or hardening. The proper annealing temperature varies with the carbon content, and the width of the critical range varies likewise.

The committee of the American Society for Testing Materials has recommended the following range in temperatures:

Carbon Content Per Cent	Annealing Temperature Range Degrees Fahr.
Less than 0.12	1607 to 1697
0.12 to 0.25	1544 to 1598
0.30 to 0.49	1399 to 1544
0.50 to 1.00	1454 to 1499

The length of time steel should be held at the annealing temperature varies with the size and shape of the piece. It is important that the piece be heated through uniformly at the annealing temperature. Where quality of output is the watchword, modern heat treatment is not attempted without first carrying out correct annealing treatments as a proper foundation for subsequent processes.

Automatic Temperature Control

With the furnace controlled automatically the perplexing question as to when the steel is heated uniformly throughout is not answered by guess, but it is clearly and definitely shown on the record of automatically controlled temperatures for the annealing cycle. Coupled with this heat control is a furnace atmosphere free from injurious products of combustion, and a heating by uniform radiation rather than by cyclonic convection blasts of hot gases met with in the ordinary fuel-fired furnace.

Forging, forming and cutting dies may be made from (1) high-carbon steels, (0.70 to 0.95 per cent carbon), hardened and drawn, or (2) from low-carbon steel (0.15 to 0.25 per cent carbon) case hardened, the latter virtually eliminating the danger, which exists with high-carbon steel, of spoiled dies, through warping and cracking.

Importance of Quenching

Ancient ideas and processes indicate clearly the fact that early steel treaters attached great importance to the nature of the fluid

in which hot steel was quenched. A work published in 1810 directs one "to take the root of blue lilies infused in wine and quench the steel in it and the steel will be hard." The same author advises that if "the juice or water of common beans have iron or steel quenched in it, it will be as soft as lead." It is said that some barrels of Sheffield water were at one time shipped to America for steel hardening purposes. Pure cold water is now usually employed for hardening. Roughly speaking, steel is glass hard when quenched in ice cold water or brine, and softer when quenched in oil or warm water. In other words, hardness is a function of the rate of cooling, the higher the rate of cooling producing the greater hardness. There are three modern theories for steel hardening, (1) the stress theory, (2) carbon theory, (3) solution theory. The stress theory points to the fact that the cold working of steel hardens it, and contends, therefore, that the high stressing of the cooled outer shell of quenched steel when shrinking upon the hot interior, and the stress of crystal change from hot to cold metal, should also produce hardness. The carbon theory contends hardness results from the carbon content changing its condition from one allotropic form to another during quenching. The solution theory and perhaps the most logical, contends that carbon is in solid solution with the iron, and from such assumption explains all heat-treating phenomena.

All theories concerning hardening, however, are united upon the necessity of heat control as outlined for annealing. Hence the electric furnace, already described as suited to annealing, may be used just as successfully for heating high-carbon steel dies which are to be hardened by quenching. No doubt can exist in the mind of the operator of the electric furnace as to the exact time when the die block, be it large or small, has reached an absolutely uniform temperature throughout. Whence, other things being normal, successful hardening can only be thwarted by improper quenching.

Case Hardening With Electric Furnace

The case hardening applied to low-carbon (below 0.25 per cent) dies is merely the outgrowth of the old cementation process, as used in making crucible steel. Here, however, instead of carburizing the metal through and through, the process ceases after

carburizing to a greater or lesser depth below the surface. The modern case hardening operation is not so simple as the crucible process. A furnace should be available whose heat is easy to regulate and maintain at a fixed uniform distribution during the whole carburizing process. It should be equipped with pyrometer, and automatic regulation of temperature is a valuable asset. Carburization may be effected in several ways but we will restrict ourselves to the pack hardening in boxes containing the carburizing material with which the parts to be treated are surrounded. For practical purposes, work is usually heated to at least 1560 degrees Fahr. and may even be brought to temperatures of 1850 to 1900 degrees Fahr. High temperature gives speed to the process but is objectionable, due to coarsening the grain of the steel and a tendency to distort the work. A good carburizing temperature 1560 degrees Fahr. has the advantage of altering the core but little, unless the process is unduly prolonged. The time of exposure depends upon size of work, depth of carbon penetration desired, per cent of carbon required in the case, carburizing agent used, temperature used, etc. Published tests on a 5/8-inch steel blank, (carbon 0.15 per cent) show the following results of penetration with temperature and a carbon content on the surface of 0.85 to 0.90 per cent with a penetration of 0.050 inches for a particular carburizer:

Time of Exposure in Hours	Penetration in Inches Degrees Fahr.		
	1550	1650	1800
½	.008	.012	.030
1	.018	.026	.045
2	.035	.048	.060
3	.045	.055	.075
4	.052	.061	.092
6	.056	.075	.110
8	.062	.083	.130

High temperature and long exposure tends to render work brittle, partly due to prolonged exposure to high temperature and partly due to relative increase in cross section of hardened area compared to the soft core.

The above remarks lead one to the conclusion that the electric furnace has important advantages for the carburization stage of the case hardening process, where it is evident that close regulation and control of temperature, as well as uniform delivery and

distribution of heat is essential for the best results. Uniformity of product requires that each part of the charge be subjected as nearly as possible to the same heat cycle, whether it be near the center of the carburizing box or near its outer walls. It has already been stated that the electric furnace with its automatic control will bring each part of a charge of material to the same temperature through the control by a surface couple on that charge. Furnaces may be designed to give practically the same heat in each carburizing box constituting the furnace charge, even though the control is actuated from a pyrometer on a single box. In other words, uniform heating conditions exist throughout the heating chamber.

Remarks already made concerning the use of the electric furnace for hardening high-carbon steel dies apply equally to heating for the quench of carburized dies.

Tempering and Drawing

The temper should be drawn on all hammer dies, to relieve strains and to give resiliency or spring resulting in better wearing qualities. An oil-tempering bath electrically heated is a most satisfactory tool, and the hardened dies should immediately go into it even before the die is quite cooled from the hardening operation. Temperature of oil bath should be about 400 degrees Fahr. In other words, hardened steel is "tempered" by being reheated to about 400 degrees Fahr. where it looses considerable brittleness and yet little of its hardness, making it suited for dies, and metal cutting tools; reheated to 480 degrees Fahr. it is less brittle and suited for use in rock drills, stone cutting tools, etc.; at 525 degrees Fahr. it is suited to dental and surgical instruments, hack saws, etc.; at 570 degrees Fahr. the maximum usually employed, it may be used for wood saws, springs, etc. Sudden cooling after tempering does not effect hardness or softness of steel, hence when taken from the oil bath, it way cool either rapidly or slowly.

Electric furnaces for heat treating drop forge dies and metal cutting tools are usually of the box type. There furnaces operate at temperatures up to and including 1800 degrees Fahr. and may be had with automatic control as previously described.

A furnace suited to heating large dies and cutters at temperatures not exceeding 1800 degrees Fahr., with automatic tem-

perature control by test has shown the following performance, compared with a similar oil-fired furnace on the same work.

	Electric	Oil-Fired
Dimensions heating chamber	30"x36"x22" high	48"x24"x20" high
Average temperature held	1450 degrees Fahr.	1400 degrees Fahr
Fuel or power to hold at 1400 degrees Fahr.	8.04 KWH.	1.65 gal. per hour
Cost per hour to hold 1400 degrees Fahr. at $1.25	$0.10	at $0.14 $0.231
Amount of steel heated per hour	84 pounds	84 pounds
Fuel or power for heating steel	13.35 KWH.	1.9 gal. per hour
Cost fuel or power per hour	$0.167	$0.266
Cost per pound heating steel	$0.199	$0.317

These results may be surprising to those who base their calculations solely on relative B.t.u. costs for oil and electricity. Were the upkeep costs included, the difference in favor of electric furnaces would increase, since in the past four years, the upkeep of this furnace has been practically nothing.

The foregoing has applied to the electric furnace for heating processes in producing drop forge dies and metal cutting tools. A much greater field for the electric furnace lies in the heat treatment of drop forgings. Here we meet again, the annealing, hardning by quenching, case hardening, and tempering or drawing processes. The metallic resistor furnace is here again ready to demonstrate its superiority in heating processes involving 1900 degrees Fahr. or less. The designs of furnaces must comply with methods of handling a production having volume and tonnage. Electric heat can be utilized with practically all types of furnaces, such as car bottom type, pusher type, conveyor type, box or tunnel type, either of vertical or horizontal construction. All furnaces may be well heat lagged without danger to refractories and at the same time secure low thermal capacity resulting in quick heating.

There has been no attempt in this paper to put forth any new heat-treating process. "Well known and accepted process specifications have in part been described only that the completeness with which the electric furnace is able to meet such conditions might be more clearly presented.

The use of the electric furnace does not call for new methods of manipulation of present heating processes, but rather fits itself into standard and generally accepted heat-treating requirements admirably, removing practically all uncertainties connected with proper application of heat; and eliminates almost entirely the handicaps inherent in fuel-fired furnaces. These handicaps of

fuel furnaces have not been discussed here, since it is believed that we are all only too well acquainted with such, due to past forced association.

In conclusion, it may be said that the electric furnace for quality heat treating, is rapidly replacing the fuel-fired furnace. Its simplicity, its dependability, its low upkeep, its improved products, and its ability to turn out repetition work free from defects, are some of the factors which contribute to economy of operation in such a degree that with prevailing rates for electric heat and fuels, the electric furnace usually shows an "over all" cost per piece which is less than that treated in the fuel-fired furnace.

The Human Element

When all has been said and done, the human element may very materially modify results. Attempts should, therefore, be made to take, so far as practical, every opportunity offered to minimize the effect of human manipulation. We refer to such things as perfect conversion of heat, met with in the electric furnace, and the automatic control of power or temperature, which is almost perfectly accomplished in the present day electric furnace.

Hand in hand with the proper selection of furnace for industrial heating processes and coincident with the selection of electric heat energy, should be well worked out specifications covering the best type, its design, size of unit, number of furnaces, their arrangement in the line of production and the grouping of auxiliary equipment, such as transportation, handling, cooling and testing.

The same definite natural laws control cooling as well as heating. Hence for successful results and low "over all" costs, it is important to have the cooling equipment given the same careful design as the heating equipment. Control must be provided, so far as is possible, to maintain required relations between temperature, cycles of heating and cooling, giving due consideration to surface exposed and underlying mass in order to get maximum quality and quantity of production and economical operation.

"Over All" Cost and Management

The effect on "over all" cost due to "form value," etc. of heat sources, (fuels and electricity) are very much veiled in practice

by wide divergence in such economic advantage, depending upon the managerial ability of the users. Under a poor management the most advantageous "form energy" may be wasteful. Electric energy, however, under good management renders substantial returns by virtue of its "form" in many industrial processes.

Progress for the future means better heating equipment; better methods of heating and better means of handling the charge both within and without of the furnace. In order to insure the best equipment let us have competent engineers to select it, then with the best operators to handle the equipment we will realize the minimum for our "over all" costs.

Discussion of Mr. Collins' Paper

MR. TURNER: I would like to ask Mr. Collins as to what price per kilowatt-hour an electric furnace could be compared in cost to a gas-fired furnace, the cost basis, and what cost one would have to buy electric current at to economically operate an electric furnace, as compared with gas.

E. F. COLLINS: I might say that one of the objects in writing this paper was to prevent people from asking that question, because it is a very difficult one to answer directly. In other words, I have pointed out in this paper, that about the last question that you should ask yourself in choosing between the electric furnace and any other type, is the question of the relative cost of B.t.u.s developed electrically and by fuel, because there are so many other considerations usually met with whose economic value is very much greater than the relative cost of B.t.u. generated electrically as compared with fuel, that is a matter of taking average values.

I have in mind one instance in which gas-heated equipment was replaced by electric in which the company could have afforded in that case to have paid 75 cents a kilowatt-hour for the electric energy as against 60-cent gas. That is, of course, an exceptional case, but in my paper, you will see that I have made a plea for a thorough study, analysis and a valuation of the advantages and the disadvantges of the electric as compared with fuel-fired equipment, before deciding which it shall be. I am not an advocate of electric heat for all purposes and in all places. As a matter of fact, some of my hardest fights have been to keep electric heating out of industrial processes where I knew it was not suited. I have always attempted in my recommendations of the electric furnace to be absolutely impartial and to make a study and analysis of the over-all proposition, the over-all cost of the finished product, and then recommend that form of heat which will give the best results considered from all angles.

As an example I recall a case of the heat treatment of a miscel-

laneous lot of dies. These ran in shop costs from perhaps $50 to $100 per die up to $1200 or $1500, and I investigated the total cost of heat treating those dies using electric heat and using oil. I found with the rates prevailing that the electric heat in this instance cost just about double that of oil for doing this work, but I also found that the total cost of the electric energy for doing that heat treating was only 0.006 of the factory cost of those dies. Our experience proved that we might expect from the electrically treated die a production that was 50 to 100 per cent in excess of the oil treated. You see you do not have to make many more punchings from the die electrically heated, to absolutely wipe out the total cost of your electric heat, to say nothing about the difference in cost.

I hope that I have made this clear, and I hope that all of you have an opportunity to read this paper, in which I have called attention to those phases which lie auxiliary to the direct cost of the B.t.u. developed electrically as compared with the cost of the B.t.u. developed by other means.

QUESTION: The main element in the cost of the electric furnace is the metallic type of resistor, and the question resolves itself into the section of resistor metal that one is able to use. I would like to know if you can tell us whether the voltages have been standardized for any type of furnace that would allow us to use a heavier section of metallic resistor?

E. F. COLLINS: Ordinarily the electric furnace should be so designed that there will be no appreciable deterioration of the metallic resistor, and it is possible to so design such furnaces, using the chrome nickel resistor that will carry up to temperatures, if you please, of about 1800 degrees Fahr. Now I don't mean to say, of course, that the deterioration at 1800 degrees Fahr. is no more than the deterioration at 1000 degrees Fahr., but the deterioration of a resistor at those temperatures is very, very slight, and so slight, in fact, that the upkeep of the furnace is usually only a fraction of the upkeep of a fuel-fired furnace of the same capacity and doing the same work.

QUESTION: The question in my mind was whether electric furnaces have been developed to a point where one can decide the proper voltage at which to operate the resistor?

E. F. COLLINS: I think you are a bit confused as to the effect of voltage on the resistor. The voltages which are used are almost universally standard voltages. The amount of heat which is put into a resistor is dependent upon its resistance and voltage applied. You can take the same size ribbon and by making a longer length of it reduce the quantity of heat, but we do run at certain densities, heat densities, on the resistor. A given number of watts per square inch of radiating surface are allowed, and we hold that value of heat

emission, or heat generation, to such a point that at its maximum appreciable deterioration of the resistor does not occur.

QUESTION: I would like to ask if the heating arrangement has ever been made that will take small voltages for heating steel for forging.

E. F. COLLINS: I have in the past operated electric furnaces which heated billets to a matter of 1200 degrees Cent. or thereabouts, but that was a carbon type of furnace which did not prove to be a commercial proposition. When it comes to applying the electric resistor to a forging proposition such as faces us today, we are not ready to talk about that yet.

THE TEMPERING OF TOOL STEELS

By J. P. Gill and L. D. Bowman

Abstract

This paper makes a study of the effect of time, temperature and mass on the tempering of tool steels, including high-speed steels. It is shown that tempering colors are dependent on time as well as temperature, and that all tempering colors can be produced on the surface of a piece of steel successively at low temperatures (250-300 *degrees Fahr.*) *if held for a sufficient length of time. It is also shown that the time element is less effective, the higher the drawing temperature, and that mass has only a small effect upon the rate of tempering.*

Molecular rearrangement takes place in hardened steels at atmospheric temperatures, the speed of which increases with the temperature, but is not proportional to the temperature.

The first measurable decrease in hardness takes place in a 1.00 *per cent carbon tool steel at a temperature of about* 275 *degrees Fahr. when tempered for a length of time not greater than two hours. The same is true for a number of light alloy tool steels. As the percentages of carbon and alloys increase, it requires a proportionally higher temperature to soften the steel, until in high-speed steel, tempering within a certain range, actually increases the hardness of the steel. The specific gravity increases and the volume decreases with the tempering of carbon and light alloy tool steels. A number of tempering diagrams are given for some standard types of tool steels.*

High-speed and carbon tool steels should be slowly cooled from the tempering temperatures. Quenching from these temperatures will produce some brittleness.

A short discussion is given of the phenomenon of "temper brittleness" as it refers to tool steels.

A paper presented before the fifth annual convention of the Society, Pittsburgh Oct. 8-12, 1923. The authors, J. P. Gill and L. D. Bowman are metallurgists with the Vanadium-Alloys Steel Co., Latrobe, Pa.

PRACTICALLY all steels and more especially tool steels, after they have been hardened, are in a strained condition and oftentimes have excess hardness. To relieve these strains, to decrease the brittleness and hardness, or to toughen, the steel is heated to a temperature considerably below its critical range. This operation is known as "tempering." The tempering of steels, simple as the operation seems, will occasionally produce effects little understood and often unexplainable. Furthermore, the tempering operation does not seem to have been given the study that its importance apparently deserves.

Temper Colors

Until recent years nearly all tempering was regulated by the so-called tempering colors, and we know that this method is still widely used in the tempering of such tools as chisels, etc. There is a fair agreement among steel treaters and metallurgists as to the temperature at which different colors appear on the surface of a piece of bright steel when it is heated.

The following table of temperature colors is the one generally accepted:

Color	Degrees Fahr.
Faint Yellow	430
Straw Yellow	460
Dark Yellow	480
Brown	500
Red Brown	510
Light Purple	530
Dark Purple	550
Blue	560
Dark Blue	570
Pale Blue-Grey	600

These colors are the result of a thin coat of oxide forming on the steel, and just as scale forming on steel at a red heat increases in thickness with time and with the temperature constant, this coat of oxide may be increased in thickness by holding at some temperature a sufficient length of time. Thus, holding a piece of steel weighing about a quarter of a pound at 500 degrees Fahr. for some forty minutes, all the temper colors can be successively produced beginning with the straw color and passing through the entire range to the blue. The following results were produced by

Brearley by heating small pieces of steel with free access to air. The figures, given below indicate the number of minutes required to produce the full color as tabulated.

	Temperature 500 Degrees Fahr.				
Color	Straw	Brown	Purple	Dark Blue	Pale Blue
Minutes	0.5	3	11	27	40

These simple experiments show that the color is as much dependent on the time as the temperature. However, the time element also has effect on the tempering of the steel, and statements have been made that the temper-color bears a true relation to the hardness of the steel regardless of how this temper-color was produced. That is, if a piece of steel shows a brown temper—color by holding at a temperature of 500 degrees Fahr. for ten minutes, and a purple color by holding at the same temperature for thiry minutes, the two pieces of steel will have the same hardness. This may be true for a number of cases, but this rule cannot be generally applied. It is best to consider that the color is only of value as an emperical guide under definite conditions.

Molecular Rearrangement of Hardened Steel

Molecular rearrangement begins to take place in hardened steels immediately after quenching and at atmospheric temperatures, in proof of which is the fact that hardened magnet steels show more constant magnetic properties six months or a year after hardening, than shortly after hardening. Also thin strips of tool steels hardened so that they remain straight, will often times warp six months or more later, though they have not been subjected to temperature changes of more than 20 or 30 degrees Fahr. Molecular changes are usually accompanied by either heat evolution or absorption, and it has been found that hardened steel in returning to its normal state, partially accomplished by tempering, gives off heat. Schottky[1] in his work on tempering steels shows this by placing hardened steels in water vapor, and even at such a low temperature notes that the temperature of the vapor increases several tenths of a degree. He finds that the evolution of heat in-

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creases with the carbon content up to a certain maximum, and then decreases. This molecular rearrangement is hastened by an increase in temperature and it has been the practice of manufacturers to quickly age their magnets by alternately placing them in boiling and freezing water. Since this molecular rearrangement is hastened by an increase in temperature, we are justified in stating it is tempering, in which case it follows that tempering takes place at atmospheric temperatures.

By holding a piece of hardened 1.00 per cent carbon tool steel ¾ x ¾ x 2 inches at a temperature of 212 degrees Fahr. for eleven days, a slight decrease in hardness took place, and during this time the entire range of temper colors was produced. The effect, however, of low temperature tempering, let us say up to the temperature of boiling water, is chiefly exhibited by the removal of internal strains and brittleness, resulting from the strains.

Tempering for a limited time, that is, two hours or less, the first definitely measurable decrease in the hardness of a hardened piece of 1.00 per cent carbon tool steel takes place in the neighborhood of 275 degrees Fahr. The same is true for most light alloy tool steels. This decrease in hardness is very small and gradual until a temperature in the neighborhood of 500 degrees Fahr. is reached, when the decrease in hardness seems to become slightly more rapid. This rate of decrease seems to remain constant up to a temperature of about 1250 degrees Fahr., when the rate of decrease slackens until the critical point of the steel is reached.

Figs. 1, 2, 3, and 4 show the effect of different temperatures on the hardness of hardened tool steels of four general types. Fig. 1 shows the curve for a straight carbon tool steel containing 1.01 per cent carbon, 0.30 per cent manganese and 0.25 per cent silicon. Fig. 2 shows the curve for a chrome vanadium steel containing 0.71 per cent carbon, 0.74 per cent chromium and 0.21 per cent vanadium. Fig. 3 shows the curve for a steel of the oil-hardening non-deforming type containing 1.03 per cent carbon, 1.09 per cent manganese, 0.48 per cent chromium and 0.18 per cent vanadium, and Fig. 4

shows the curve for a steel containing 1.11 per cent carbon, and 1.25 per cent tungsten.

As the percentages of carbon and alloys in the steel increase, it requires a higher temperature to proportionately

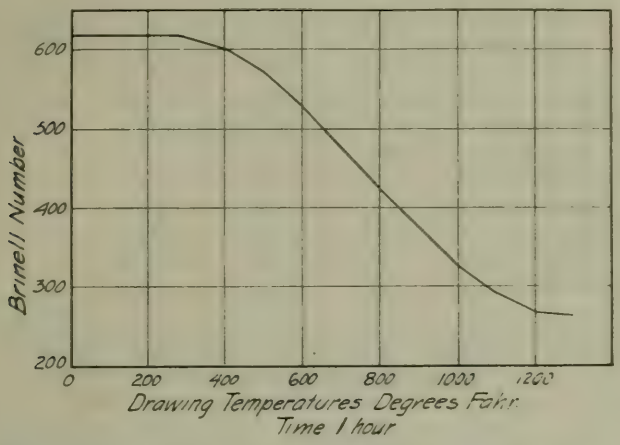

Fig. 1—Curve Showing the Effect of Various Tempering Treatments on the Brinell Hardness of a Hardened Carbon Steel having the following Analysis: Carbon, 1.01 per cent; Manganese, 0.30 per cent; Silicon, 0.25 per cent. Hardened by Quenching in Water from 1425 degrees Fahr.

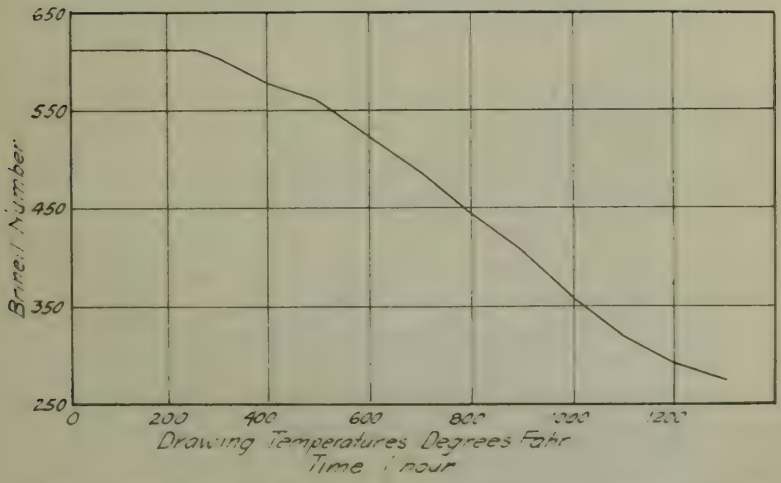

Fig. 2—Curve Showing the Effect of Various Tempering Treatments on the Brinell Hardness of a Chrome-vanadium Steel having the following analysis: Carbon, 0.71 per cent; Chromium, 0.74 per cent; Vanadium, 0.21 per cent. Hardened by Quenching in Water from 1425 degrees Fahr.

soften the steel until the percentage of alloys becomes so great that a pure or nearly pure austentitic structure is produced by hardening. Tempering a steel of this kind within a certain range, will actually increase its hardness. This is

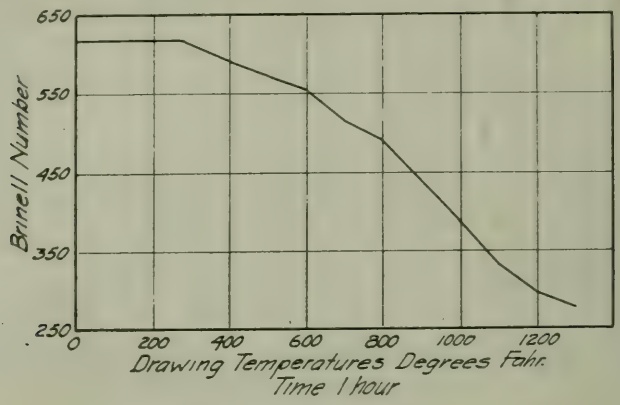

Fig. 3—Curve Showing the Effect of Various Tempering Treatments on the Brinell Hardness of an Oil-hardening Steel having the following analysis: Carbon, 1.03 per cent; Manganese, 1.09 per cent; Chromium, 0.48 per cent; Vanadium, 0.18 per cent. Hardened by Quenching in Water from 1450 degrees Fahr.

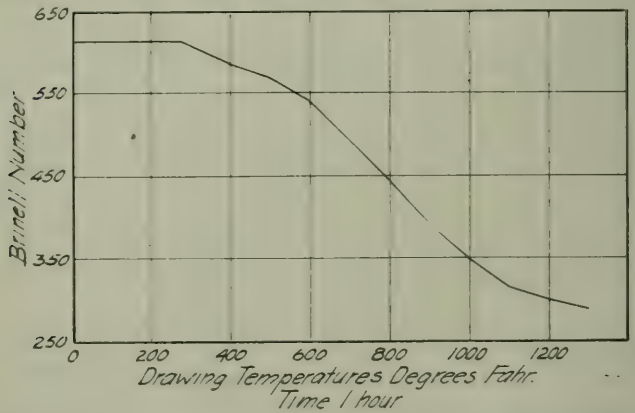

Fig. 4—Curve Showing the Effect of Various Tempering Treatments on the Brinell Hardness of a Tungsten Steel having the following partial analysis: Carbon, 1.11 per cent; Tungsten, 1.25 per cent. Hardened by Quenching in Water from 1450 degrees Fahr.

especially noticeable in high-speed steel that has been properly hardened. The structure before tempering is almost wholly austenitic, but on heating within a certain range the austenite

is changed to martensite, which is a harder structure than austenite. Thus we have an increase in hardness, which is often referred to as "secondary hardness." Fig. 5 shows the effect of the drawing temperature on the hardness of high-speed steel.

The length of time a piece of hardened steel is held at the drawing temperature greatly affects its hardness. This effect becomes less noticeable with a higher drawing temperature, which is apparently due to a combination of causes,

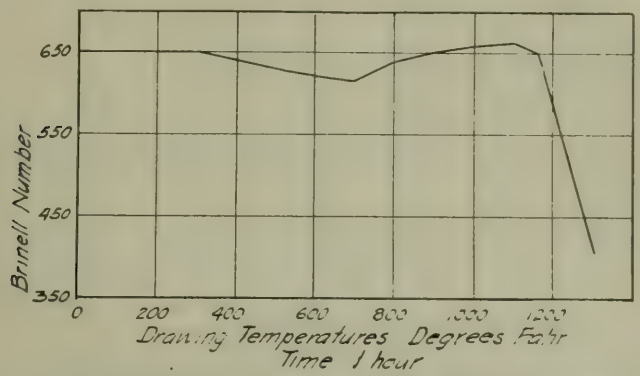

Fig. 5—Curve Showing the Effect of Various Tempering Treatments on the Brinell Hardness of a High-speed Steel Hardened at 2350 degrees Fahr., having an approximate analysis of Carbon, 0.68 per cent; Chromium, 4.00 per cent; Vanadium, 1.00 per cent; Tungsten, 18.00 per cent.

among which are, that the rate of heat penetration into a piece of steel is faster as the temperature increases and also that the time factor has greater possiblilities of demonstration at the lower temperatures, inasmuch as the steel is in its most unstable condition.

According to Barus and Strouhal[2], to each tempering temperature there corresponds a maximum tempering effect which is the more quickly reached the higher the temperature. This is true for all practical purposes since the amount of tempering which takes place in one or two hours after the first four hours of tempering, is exceedingly small. When carrying the length of time to extremes, and drawing for days and even weeks, there is still a slight further decrease

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in hardness. Where this decrease in hardness would stop, cannot be answered. The maximum tempering effect at 350 degrees Fahr. is practically accomplished on a 1.00 per cent carbon steel 1 inch square, in about four hours, this time decreasing rapidly as the tempering temperature increases, so that at a temperature of 1000 degrees Fahr. one hour appears sufficient to obtain the practical maximum tempering effect. Fig. 6 shows the tempering of the same four steels which were

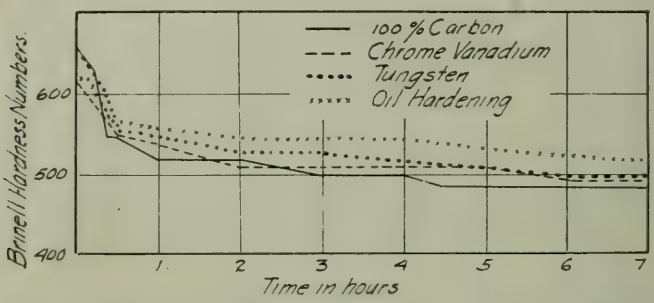


Fig. 6—Shows the Brinell Hardness Curves of the Four Steels of Figs. 1, 2, 3 and 4 when Tempered for Varying Lengths of Time at 600 degrees Fahr.

used for showing the effect of different tempering temperatures, held different lengths of time at a temperature of 600 degrees Fahr.

Effect of Mass on Rate of Tempering

Mass has only a small effect upon the rate of tempering, that is, if the practical maximum tempering effect were obtained at a certain temperature in one hour with a specimen having a volume of 1 cubic inch, it would require practically the same time to obtain the same tempering effect with a specimen of the same steel having a volume of 16 cubic inches. Five different size blocks, each a cube, were made of four types of tool steels. Each set of blocks were so hardened that all had practically the same initial hardness. The specimens were drawn in a liquid bath and held at the actual temperatures given, for the time given. Tables Nos. I, II, III and IV show the results obtained.

Upon the initial hardness of a piece of steel partially de-

pends its hardness after drawing. For instance, a piece of steel of such analysis which can be made file-hard by quenching in water, and showing a Brinell hardness of some 650, let us say will only show a Brinell hardness of 550 by quenching in oil, and by still slower cooling a Brinell of 450. The initial hardness then of these three pieces of steel of the same

Table I

Effect of Mass on the Rate of Tempering an Alloy Tool Steel

	——Size of Specimen——				
Drawn at	1-inch cube Brinell number	1½-inch cube Brinell number	2-inch cube Brinell number	3-inch cube Brinell number	4-inch cube Brinell number
600 degrees Fahr. for 30 min....	567	567	567	578	578
600 degrees Fahr. for 60 min....	542	542	555	555	555
600 degrees Fahr. for 120 min....	524	524	532	542	532
800 degrees Fahr. for 30 min....	468	477	477	477	477
800 degrees Fahr. for 60 min....	452	460	460	460	460
800 degrees Fahr. for 120 min....	444	452	452	452	452
1000 degrees Fahr. for 30 min....	387	395	402	395	402
1000 degrees Fahr. for 60 min....	364	375	375	364	364
1000 degrees Fahr for 120 min....	351	364	375	364	364

Analysis of Steel

Carbon, 0.72 per cent, manganese, 0.18 per cent; phosphorus, 0.011 per cent; sulphur, 0.012 per cent; silicon, 0.23 per cent; chromium, 0.73 per cent; vanadium, 0.18 per cent.

analysis being respectively 650, 550 and 450 if then drawn to different temperatures, give us results similar to those shown in Fig. 7 ideally made from the results obtained from several different steels.

Volume Changes

Let us next consider the volume changes produced by tempering. Nearly all tool steels expand on hardening. That is, they show a greater volume and lower specific gravity. Though there are steels which may contract on hardening, careful specific gravity measurements of most tool steels will show a lighter material after hardening than before, or that the volume of the steel has increased. Metcalf and Langley[3] have compiled the figures in Table V of the specific gravities for hardened steels of different carbon contents.

From this table it may be stated that the volume of a straight

3. The Hardening and Tempering of Steel - F. Reiser, P. 28.

carbon steel increases with the carbon content. It would then be expected, and it is true, that tempering carbon and light alloy steels increases their specific gravity, and therefore lessens the volume, or in other words causes them to shrink. Fromme[4] has determined the specific gravity of a rod 0.16 inch in diameter hardened and tempered at various temperatures. Taking the volume of the annealed rod as unity, he obtains the figures shown in Table VI.

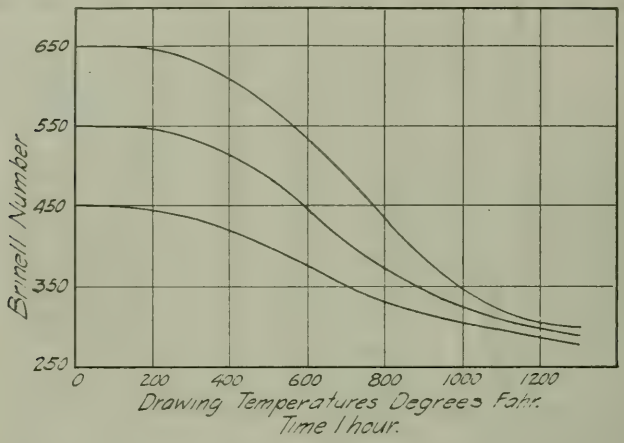


Fig. 7—Curves Showing the Effect of Varying Drawing Temperatures upon the same Composition Steel when Initially Hardened in Mediums yielding Brinell Hardness Figures of 650, 550 and 450, respectively.

Physical Properties

The physical properties of hardened tool steels including the tensile strength, elastic limit, percentage of reduction in area, and the percentage of elongation, are but a poor index to the properties of the steel until they have been given a sufficient tempering, to at least give a low definite figure for reduction in area. This is quite evident since when there is no measurable reduction in area or elongation, the tensile properties of the steel are likely to prove erratic. Thus the physical properties (just named) of hardened tool steels usually have little importance until they have been drawn to a temperature in excess of some 650 degrees Fahr., since at

4. The Hardening and Tempering of Steel—F. Reiser, P. 32.

this temperature little or no martensite seems to remain in carbon and light alloy steels, and going above this temperature troosite begins to decompose into the constituent characteristic of steels in their toughest state, sorbite. Bullens

Table II

Effect of Mass on the Rate of Tempering an Alloy Tool Steel

	——Size of Specimen——				
Drawn at	1-inch cube Brinell number	1½-inch cube Brinell number	2-inch cube Brinell number	3-inch cube Brinell number	4-inch cube Brinell number
800 degrees Fahr. for 30 min.	532	542	532	542	542
800 degrees Fahr. for 60 min.	524	524	524	532	524
800 degrees Fahr. for 120 min.	512	512	512	524	512
1000 degrees Fahr. for 30 min.	437	437	444	444	437
1000 degrees Fahr. for 60 min.	424	424	430	430	424
1000 degrees Fahr. for 120 min.	402	402	410	410	410

Analysis of Steel

Carbon, 0.98 per cent; manganese, 0.21 per cent; phosphorus, 0.015 per cent; sulphur, 0.013 per cent; silicon, 0.26 per cent; chromium, 4.07 per cent.

Table III

Effect of Mass on the Rate of Tempering a Carbon Tool Steel

	——Size of Specimen——				
Drawn at	1-inch cube Brinell number	1½-inch cube Brinell number	2-inch cube Brinell number	3-inch cube Brinell number	4-inch cube Brinell number
600 degrees Fahr. for 30 min.	567	567	567	555	567
600 degrees Fahr. for 60 min.	542	555	567	542	555
600 degrees Fahr. for 120 min.	532	542	555	542	542
800 degrees Fahr. for 30 min.	452	452	460	460	452
800 degrees Fahr. for 60 min.	437	444	437	452	444
800 degrees Fahr. for 120 min.	430	437	430	444	437
1000 degrees Fahr. for 30 min.	382	387	382	382	387
1000 degrees Fahr. for 60 min.	346	357	351	346	351
1000 degrees Fahr. for 120 min.	340	351	351	346	346

Analysis of Steel

Carbon, 1.04 per cent; manganese, 0.23 per cent; phosphorus, 0.017 per cent; sulphur, 0.008 per cent; silicon, 0.26 per cent.

designates the temperatures lying between 750 and 1250 degrees Fahr. as the toughening range of steel, and it is steels tempered only in this range upon which we will consider the effect of the tempering on the physical properties. Each increase in temperature in this range lowers the tensile strength and elastic limit, but with a corresponding increase

in the ductility. The ratio of the tensile strength to the elastic limit remains quite constant until a temperature of about 1300 degrees Fahr. is reached, when the elastic limit begins to decrease faster than the tensile strength, the greatest difference resulting in the annealed steel.

Temper Brittleness

Further consideration of the physical properties to include the impact strength brings us to the discussion of a phenom-

Table IV

Effect of Mass on the Rate of Tempering a High-Speed Tool Steel

	——Size of Specimen——				
Drawn at	1-inch cube Brinell number	1½-inch cube Brinell number	2-inch cube Brinell number	3-inch cube Brinell number	4-inch cube Brinell number
1200 degrees Fahr for 30 min....	591	600	591	600	600
1200 degrees Fahr. for 60 min....	578	578	578	591	578
1200 degrees Fahr. for 120 min....	542	555	555	578	555
1300 degrees Fahr. for 30 min....	402	402	402	402	...
1300 degrees Fahr. for 60 min....	375	382	370	382	...
1300 degrees Fahr. for 120 min....	364	364	370	375	...

Analysis of Steel

Carbon, 0.69 per cent; manganese, 0.21 per cent; phosphorus, 0.022 per cent; sulphur, 0.003 per cent; silicon, 0.23 per cent; tungsten, 18.20 per cent; chromium, 4.13 per cent; vanadium, 1.15 per cent.

Table V

Specific Gravity of Steels Having Different Compositions

Percentage of Carbon	Sp. Gr. of the ingot	Sp. Gr. of the annealed bar	Sp. Gr. of the steel hardened at a red heat	Sp. Gr. of the steel hardened at a yellow heat
.529	7.841	7.844	7.826	7.814
.649	7.829	7.824	7.849	7.811
.841	7.824	7.829	7.808	7.784
.871	7.818	7.825	7.773	7.755
1.005	7.807	7.826	7.789	7.749
1.079	7.805	7.825	7.798	7.741

enon which at present is unexplainable. This phenomenon is the "temper brittleness" of steels.

In the investigations[5] of material for the construction of airplanes and airplane engines by the British government, Brearley called their attention to the "temper brittleness" phenomenon which occurred particularly in chrome nickel

5. Report on the Materials of Construction Used in Aircraft and Aircraft Engines—P. 23.

steels. This phenomenon exhibited itself to a high degree in a steel containing 0.33 per cent carbon, 3.71 per cent nickel and 0.91 per cent chromium. By hardening this steel and then tempering to 1200 degrees Fahr. and cooling slowly, it gave an Izod impact value averaging only four for a number of samples. Instead of cooling slowly from 1200 degrees Fahr.

Table VI

Specific Gravity of Rod Hardened and Tempered at Various Temperatures

Condition of rod	Volume of rod 0.16 inch in diameter
Annealed	1.00000
File hard	1.01000
Tempered at yellow	1.00492
Tempered at blue	1.00425
Tempered at grey	1.00060
Tempered very high	1.00055

Table VII

Izod Impact Tests on Standard V-Notched Bars

The bars were heated to 1200 degrees Fahr. for 30 minutes, cooled to and quenched in water from the temperatures shown in each column. The results are given in foot-pounds.

Analysis of steels tested	1200 degrees Fahr.	1050 degrees Fahr.	900 degrees Fahr.	750 degrees Fahr.	600 degrees Fahr.
1.00% C, .005% S .31% Si, .02% P .23% Mn, .00% Cr	9	8	9	13	14
.51% C, .010% S .31% Si, .015% P .30% Mn, .80% Cr .21% Va	52	62	64	77	79
.71% C, .012% S .33% Si, .011% P .18% Mn, .73% Cr .17% Va	66	72	73	82	82

but by quenching in water from this temperature, the average Izod impact number was 48, or twelve times the figure obtained by slow cooling, while at the same time the other physical properties remained the same. This so-called "temper brittleness" was not noticed until the steel was tempered to a temperature in excess of 750 degrees Fahr. and showed its greatest effect when the steel was tempered to 1100 degrees Fahr. Fig. 8 shows this effect exhibited in another nickel-chrome steel. The steel was first hardened, then tempered

to 1200 degrees Fahr. and then slowly cooled to the temperature shown, and quenched in water from these temperatures. This phenomenon was further investigated by others and reported on at the fall meeting 1923 of the British Iron and Steel institute, by Rogers and Greaves in two separate papers. Rogers reported that "temper brittleness" existed in low carbon steels, nickel steels and chrome vanadium steels.

The authors of the present paper have extended this investigation to several types of tool steel. A number of speci-

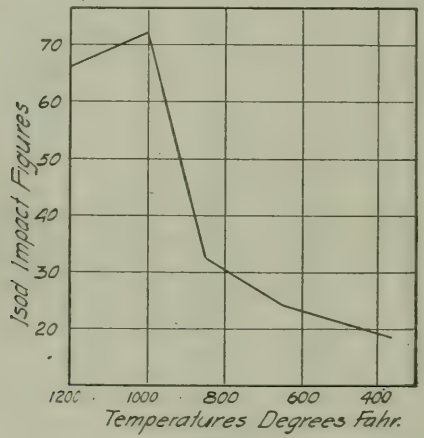


Fig. 8—Shows the Effect of Temper Brittleness upon the Izod Impact Values of a Nickel-chromium steel.

mens were made according to the Izod standard, that is, 10 millimeters square with a V-notch 2 millimeters deep, having a small radius at the bottom. All the specimens of each type of steel were hardened as nearly as possible under identical conditions. The different lots of specimens were drawn and quenched with the results as shown in Tables VII and VIII. It will be seen from these results that not one of the steels exhibited "temper brittleness," and a preliminary investigation of a number of other tool steels showed similar results. Furthermore, Table VIII shows that quenching from the drawing temperature in most cases gave lower impact values. Six specimens of an 18 per cent tungsten high-speed steel ⅝ inch square, were hardened under the same conditions

from a temperature of 2325 degrees Fahr. and drawn to 1100 degrees Fahr. for twenty minutes. Three of the specimens were slowly cooled and the others quenched from the drawing temperature. Following are the average impact results obtained:

Cooled Slowly	Quenched in Water
83	68

From these results, it is evident that both high-speed and carbon tool steels should be slowly cooled from the drawing temperature.

Tools should be tempered as soon as possible after hardening, and should be heated uniformly and slowly during

Table VIII

Izod Impact Tests on Standard V-Notched Bars

Upper row of figures are the results obtained by heating to and quenching in water from the temperatures shown.

Lower row of figures are the results obtained by heating to and cooling slowly from the temperatures shown.

Analysis of steels tested	1200 degrees Fahr.	1050 degrees Fahr.	900 degrees Fahr.	750 degrees Fahr.	600 degrees Fahr.
1.00% C, .31% Mn, .25% Si..	9	5	4	4	3
.005% S, .02%P, .00% Cr..	12	8	6	4	2
.51%C, .31% Si, .30% Mn..	52	33	20	10	13
.010% S, .015% P, .80% Cr..	76	44	25	14	10
.21% Va					
.71% C, .33% Si, .18% Mn..	66	58	12	4	..
.012% S, .011% P, .73% Cr..	82	57	18	3	..
.17% Va					

the tempering operation, this being more especially true if the tool is complicated and has thin sections and sharp projections.

Tempering Methods

Tempering methods are quite varied, and many may have their usefulness. The use of the tempering plate made of cast iron and heated from beneath, and the judging of the tempering of the tool from its color, is a very old method and one which is not any too exact. The sand bath method of packing the tools in sand in a suitable container and measuring the temperature of the sand with a thermometer or thermo-

couple, is reasonably satisfactory. It seems, however, that the liquid bath method is for general tempering work, the best. The liquid used depends on the temperatures necessary. Oil may be used up to a temperature of 500 degrees Fahr., and somewhat higher, as mineral oil can be obtained having a flash point of 600 degrees Fahr. For temperatures between 450 and 1000 degrees Fahr. a mixture of two parts KNO_3 and three parts $NaNO_3$ may be used. For temperatures from 650 to 1500 degrees Fahr. lead may be used, or by adding eight parts of tin or antimony to fourteen part of lead, it becomes liquid at 420 degrees Fahr. The liquid should be placed in a suitable container preferably one well insulated, and should be heated by some method that is uniform and easy of control. A wire basket should be provided and the pieces to be tempered placed in it and the whole lowered into the liquid, which should be at a reasonably low temperature. The whole should then be heated to the tempering temperature. This is much better than having the bath at the desired tempering temperature, and then suddenly placing the tools in it. This sudden heating tends to produce new stresses which must in turn be overcome.

Discussion of Messrs. Gill and Bowman's Paper

CHAIRMAN MERTEN: Gentlemen, we now have this paper entitled the *Tempering of Tool Steel*, open for discussion.

MR. TURNER: I would like to ask the speaker whether there would be any difference on the drawing of high-speed steel, between the regular tungsten and the cobalt steels; he showed there the highest hardness at about 1500 degrees Fahr.; now would a cobalt high-speed steel show any change at the same temperature?

J. P. GILL: The tempering diagram of a cobalt steel is practically the same as an 18 per cent tungsten steel.

MR. TURNER: You would, therefore, figure on the same drawing, for both?

J. P. GILL: Yes.

A. H. d'ARCAMBAL: Messrs. Gill and Bowman have shown quite clearly that the low tungsten type of tool steel, that is, a 1.25 or 1.5 per cent tungsten type, resists tempering no better than does the plain carbon type of tool steel.

It might be of interest to say that some small tool manufacturers have put on the market, taps made of this 1.25 per cent tungsten tool steel and called them semi-high speed steel taps. This is a misnomer, because

such tools have absolutely no more high-speed properties than does a plain carbon tool steel tap. Moreover, the majority of the low tungsten tool steels on the market contain about one-half of one per cent chromium and this means that the steel will resist tempering at a lower temperature than the plain carbon tool steel. For example, tools made of plain carbon tool steel drawn to 400 degrees Fahr. are practically file hard, that is, drawn to temperature and then taken out of the bath, whereas tools made of this low tungsten one-half of one per cent chromium tool steel, can be filed without difficulty when drawn to the same temperature in the same manner.

I would like to ask Mr. Gill what experience he has had in tempering high-speed steel for various periods of time at approximately 1100 degrees Fahr. If a tool were file hard after being drawn for 30 minutes at 1100 degrees Fahr. would it still be file hard when drawn at 1100 degrees Fahr. for one hour, two hours, three hours, etc.?

J. P. GILL: We tempered steels for periods of one week and did not find a decrease in file hardness. It seemed, however, that from one-half to one hour the maximum effect was obtainable.

A. H. d'ARCAMBAL: I believe in Table V you showed that heating to 1200 degrees Fahr. and then cooling slowly to 1000 degrees Fahr. and quenching, you obtained a higher impact value than you did when quenching directly from 1200 degrees Fahr. How did the tensile properties compare on the two?

J. P. GILL: We did not obtain the tensile properties. However, it is likely there would be little difference. The results reported by Harry Brearley show practically the same tensile strength for specimens that showed temper brittleness as for those of the same analysis, not showing this phenomenon.

A. H. d'ARCAMBAL: Would it not be good practice, then, to obtain greater toughness by cooling down slightly before quenching, so as to increase the impact value without changing the static tensile properties?

J. P. GILL: For a tool steel, it would.

A. H. d'ARCAMBAL: You obtained these results on chrome-vanadium, S. A. E. 6150 steel, did you not?

J. P. GILL: All of the chrome-vanadium steels we tested were more brittle when quenched from the drawing temperatures than when cooled slowly. By cooling slowly is meant cooling freely to room temperature without an air blast and also without burying in any insulating medium.

CHAIRMAN MERTEN: The test bar used for the impact test was a standard notched bar, was it not?

J. P. GILL: It was a notched bar.

CHAIRMAN MERTEN: Probably some of your results that showed a failure on quenching from the higher heat could be attributed to the notched bar.

J. P. GILL: We took an average of several tests.

CHAIRMAN MERTEN: Would you find the same results on a solid bar?

J. P. GILL: We used a solid bar 5/8 inch square for the high-speed steels and obtained similar results.

A. L. DAVIS: Since your test was largely confined to drawing temperatures of 650 degrees Fahr. and above, you were in a range higher than that generally used in tempering plain carbon tools, and hence you cannot draw any conclusions as to that. Nevertheless, it occurs to me that the figures that you report for 650 (or perhaps in some cases the next higher temperature) did have a trend for the quenched samples to show up better than the slowly cooled ones; that is, they would show 3 as against 2. Getting it down so small, perhaps it is difficult to draw conclusions, anyway,—but do not your figures suggest a tendency in such steels, when drawn at the lowest temperatures, to develop temper brittleness?
drawn at the lowest temperatures, to develop temper brittleness?

J. P. GILL: No, I can not say that they did. At the lower drawing temperatures most of the steels were file hard and consequently broke very sharply when struck. Therefore, a difference of one or two points, with the impact value so low cannot indicate much. If temper brittleness should exist in tool steels, we would expect to find it somewhere between 600 and 900 degrees Fahr., but this was not the case.

A. L. DAVIS: Was it not a fact that in almost every case at the 650-degree draw, a slightly lower strength was shown than on the slowly cooled pieces.

J. P. GILL: Yes, there was a slight difference, but so little we did not attach any importance to it.

W. D. FULLER: You say that you distinguished a decrease in hardness in the metal drawn at 212 degrees Fahr.?

J. P. GILL: Yes, after 11 days. We kept the specimens in a thermostat at 212 degrees Fahr. and removed the specimen once every 24 hours to measure the hardness.

A. H. d'ARCAMBAL: We have found that a one-half per cent chromium tool steel drawn for about 8 hours at 212 degrees Fahr. can be filed without much difficulty. A plain carbon tool steel drawn for the same time will be file hard after the test, showing that chromium tends to produce tempering at a lower temperature.

PROF. O. W. ELLIS: It has been clearly indicated that a decrease in hardness occurred. It appears that some work is required to connect up the rate of cooling of steel with the subsequent hardness on tempering. A large number of experiments have been carried out, which have shown that test pieces of approximately the same size as those dealt with by Mr. Gill, increase in hardness at the low drawing temperatures. Take for example, the work of Brinell, reported to the Iron and Steel institute in 1901—work that is probably the most exhaustive on heat treating that has ever been carried out—I think that in practically every instance he discovered an increase in tensile strength to occur on drawing subsequent to water quenching and a decrease in tensile strength on drawing sub-

sequent to oil quenching. It appears that some connection needs to be made between, first, rates of quenching, second, hardness subsequent to quenching, and third, hardness subsequent to tempering after varying rates of quenching.

J. P. GILL: The specimens were hardened according to the recommended treatment for hardening the steel when it was to be used for tools and dies. No attempt was made to harden the steel by unusual methods to obtain an austenitic structure which would, of course, first show an increase in hardness when drawn.

J. W. SMITH: All these tests were conducted in an oil bath, as I understand it.

J. P. GILL: Some with oil, others with salt and lead. For the low temperatures we used oil, and above 650 degrees Fahr. we used salt or lead.

H. J. FRENCH: I have been much interested in Mr. Gill's paper, and I assume that he has used in all cases a hardening practice similar to that which is customarily used in practice in hardening the various steels. However, the discussion which has taken place appears to me to make desirable some mention of the fact, that the characteristics of the hardness-tempering temperature curves for tool steels are largely dependent upon the original hardening treatment given the steel of a given composition and given size. For example, a one per cent carbon steel, which is hardened from a temperature such as is customarily used in practice, may show a decrease in hardness with rise in tempering temperature; however, if that steel is heated to a high enough temperature and then quenched, we may get at first, increase in hardness with rise in tempering temperature.

I noticed in the charts which were shown here today the original hardening treatments were not specified. I assume, of course, that in the manuscript those are given in detail. One chart was shown having three hardness-tempering temperatures curves. I think one began at 650, another began at 450, another one at a lower hardness. I did not understand whether that was to represent the effect of mass or whether it was to represent experiments relating to the effect of the original cooling medium. Of course, the two of them are more or less interrelated.

J. P. GILL: It was to show the effect of drawing on samples of the same analysis having a different initial hardness, this hardness produced by the rate of cooling.

H. J. FRENCH: If a one per cent carbon steel is hardened in water, the ratio of the elastic limit to the tensile strength is very much greater than the same elastic ratio when the steel is quenched in oil, even though comparisons are based upon a fixed tensile strength or hardness value, or a fixed elastic limit value. I think that point is rather important in relation to this question of brittleness.

J. P. GILL: Yes, it is.

A. H. d'ARCAMBAL: Have you ever conducted tensile tests on ¼-inch

diameter carbon tool steel wire, quenched in oil as compared with brine quenched specimens?

J. P. GILL: No.

A. H. d'ARCAMBAL: Both treatments will give file hard specimens. I was wondering how the toughness values would show on such specimens.

H. J. FRENCH: At the close of the World war there was appointed under the National Research council a committee which was first known as a Blue Heat committee. This committee was concerned with a study of the so-called temper brittleness or "Krupp Krankheit" of structural carbon and alloy steels. In looking over Mr. Gill's charts I find that the highest impact values were in all cases, or nearly all cases, obtained on a slow cool from the draw. As I remember the results obtained by this committee, not particularly in their own tests, but in summarizing the work of other investigators, they found in a majority of cases that the highest impact values were obtained in samples which were quenched from the drawing heat.

However, several cases came up, or came to their attention, where results consistent with Mr. Gill's results were shown, that is, the slow cool gave the highest impact values. I would like to ask Mr. Gill whether in his experience he has found that the slow cool or the quench from the drawing heat gives the highest impact value, or whether the question has been settled?

J. P. GILL: Our investigation was absolutely in the field of tool steels. We did not attempt to investigate the steels which Brearley and others report as showing the phenomenon of temper brittleness. The tool steels which we investigated, nearly all of which could be made file hard by ordinary hardening methods, showed a lower impact value by quenching from the drawing temperature. We do not believe there is any doubt but that many steels particularly of the chrome-nickel type are tougher by quenching than by slow cooling.

H. J. FRENCH: Is there a possibility that the higher impact values on the slow cool are a result of the longer time at which the sample is hot, although not at a constant temperature?

J. P. GILL: That is possible; but not likely to have had a marked effect since all the specimens were held at the drawing temperature for 30 minutes before cooling.

QUESTION: Is there any relative metallographic constituent present in each of those steels that will give a minimum temper brittleness and a minimum impact value?

J. P. GILL: We were not able to locate any.

CHAIRMAN MERTEN: Temper brittleness is usually connected with a brittleness at some lower temperature than Mr. Gill employed; 600 or 700 degrees Fahr., is the brittle range, and not 1100 or 1200 degrees. I believe that has considerable to do with the results obtained.

J. P. GILL: We report from 600 to 900 degrees Fahr. as the range.

J. STRAUSS: Small variations in hardness have a very great effect

upon the impact value of hard steel, and I just wonder whether Mr. Gill has checked up the results that he has shown for slow cooling as against rapid cooling in order to see what changes in hardness have occurred, and whether such changes, if they occurred, have not a definite relation to the increase in his impact values.

Another point is that it is really not fair to compare one heat of one steel, that is, of one composition, with another single heat of another composition. Heats of steel even made by the same process, depending upon how that process has been carried out, will show impact values which differ very widely, even under the same conditions of mechanical and thermal treatments, etc.

J. P. GILL: Hardness tests made on the specimens slowly cooled and the specimens quenched showed the same. We also took an average of a number of specimens.

J. STRAUSS: I was thinking not of a number of specimens from the same heat, for melting and rolling conditions will change from heat to heat, but of different heats of steel of the same analysis. That may have a very important effect upon the impact value as determined by the Izod test.

J. P. GILL: The results were similar for a number of steels of widely different analyses, and since these results were similar, we would hardly expect different results from steels of like analyses but of different heats.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION 102. *How can the warping of high-speed steel tools be eliminated during the hardening operation?*

QUESTION 103. *What is the effect of clay luting on alloy carburizing boxes?*

QUESTION 104. *In the forging of ring gears, does the number of blows of the hammer have any effect upon the warpage of the gear in the hardening operation?*

QUESTION 105. *Through what mechanism does vanadium retard the penetration of hardness in vanadium steels in the hardening operation?*

QUESTION 106. *What are the effects of the products of combustion upon both carbon and high-speed steel, when heat treated in open furnaces heated with city gas, coal, coke, fuel oil, etc.*

ANSWERS TO OLD QUESTIONS

QUESTION NO. 67. What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?

ANSWER. By James Sorenson, metallurgical engineer, the Four Wheel Drive Auto Co., Clintonville, Wis.

Greater hardness is obtained from quenching at the same tem-

perature in salt brine than from quenching at the same temperature in water. This is due to the difference in the heat dissipating power possessed by these substances.

Brine produces rapidity in quenching and consequently maximum hardness. However, cold brine should not be used for quenching thin pieces of complicated design, as the shock from so drastic quenching mediums is liable to cause serious distortion, or cracks which would render the piece being heat treated useless.

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel?

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

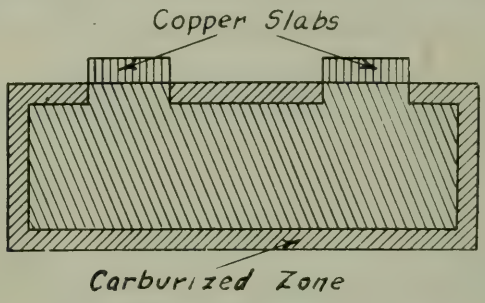
QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

ANSWER. By W. J. Merten, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

The protection of iron and steel by copper plating against

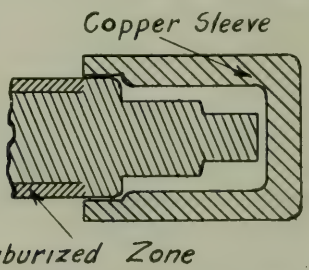
absorption of carbon from carbonaceous gases is only partially successful, due to the porosity of the copper deposit, its tendency to flake, its variation and limit of thickness, and the cost to protect the rest of the part from copper plating.

The placing of solid copper bodies against surfaces or into holes to be left uncarburized, has been found to inhibit carburiza-



Sketch Showing the Manner in which Copper Slabs when placed upon a Steel Block, Prevents Carburization.

tion very effectively. A loosely fitting, pure copper pin (1/64 inch loose or even more) can be relied upon to give proper protection and the line of demarcation of area or zone of activity of carbon monoxide gas is quite sharp. External copper sleeves or caps 1/8



Sketch Showing the use of a Copper Cap over the End of a Shaft.

inch thick placed over ends of cam shafts and automobile parts have proven very useful. One-quarter inch thick blocks of pure copper placed or laid on plates or die surfaces were entirely successful in preventing any creeping of the carburized portion. Copper

probably absorbs CO and its presence induces negative catalysis, preventing formation of Fe_3C or possibly interaction of Fe and C.

A large number of tests have been made verifying the utility of solid copper bodies in this respect. The copper is also perpetually recuperating, discharging the absorbed gases on cooling and reheating, so that on standard work it can be used continuously, over and over again.

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

ANSWER. By James Sorenson, metallurgical engineer, the Four Wheel Drive Auto Co., Clintonville, Wis.

The reduction of area in a tensile test specimen refers to the area at the point of rupture, it is usually expressed in percentage. The percentage of reduction of area is found by dividing the difference between the original cross section of area before fracture and the least cross section of area at the point of fracture, by the original cross section of area.

It is usually used as a measure of the ductility of the material and many engineers regard the reduction of area as more reliable for this purpose than the elongation.

QUESTION NO. 93. What are the more common methods of quenching ordinary taps? Are they quenched all over and the shanks drawn, or are they quenched only on the threaded portions; or are both the threaded portions and the tangs quenched, leaving the center portion of the shank soft?

QUESTION NO. 95. What is meant by "self-hardening" steels?

ANSWER. By James Sorenson, metallurgical engineer, the Four Wheel Drive Auto Co., Clintonville, Wis.

The term self-hardening steel usually refers to high-speed steel of the cementitic class, which if heated to the proper hardening

temperature and then allowed to cool in air will retain the dissolved carbides in the martensitic condition.

QUESTION NO. 96. Can the structure of a piece of steel be determined by the microscope applied to the fracture of a cross section, without polishing and etching the fracture, say of a stamping die 6 x 2 x 3½ inches, that has been hardened and broken in half, that is, are the different structural phenomena known as austenite, martensite, sorbite, ferrite, etc., so determinable?

QUESTION NO. 97. What degree of heat is required to change austenite to martensite, troostite, etc?

ANSWER. By James Sorenson, metallurgical engineer, the Four Wheel Drive Auto Co., Clintonville, Wis.

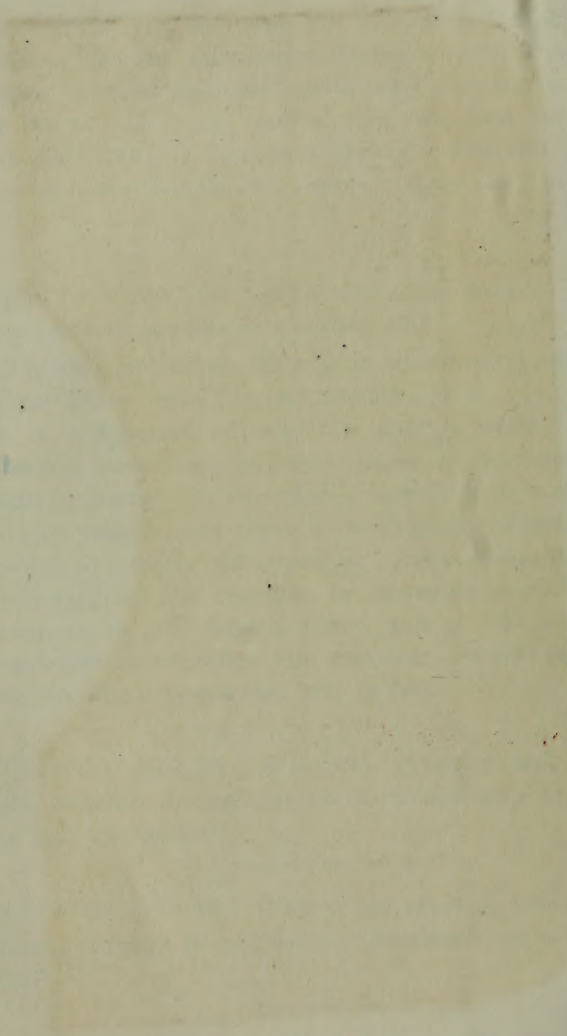
This is a question on which it may be rather difficult to give a definite answer as the exact nature of martensite has not been definitely settled, but the opinion usually held is that martensite is a solid solution and there is considerable evidence available which seems to justify this opinion. According to Professor Albert Sauveur[1] all the austenite in austenitic steel is converted into martensite at 200 degrees Cent., and at 400 degrees Cent. all the martensite is converted into troostite. At 600 degrees Cent. all of the troostite is converted into sorbite.

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

QUESTION NO. 99. What is the effect of barium carbonate and sodium carbonate in carburizing compounds, on alloy carburizing boxes?

QUESTION NO. 100. What action results from the addition of varying amounts of aluminum and ferrosilicon to steel while casting?

1. See the Metallography and Heat Treatment of Iron and Steel by Professor Albert Sauveur, 1916, page 300.



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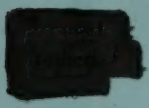

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